MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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VOL. XXXI.

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GEOLOGY OF THE SON VALLEY IN THE REWAH STATE AND OF PARTS OF THE ADJOINING DISTRICTS OF JABALPUR AND MIRZAPUR, *by* R. D. OLDHAM, A.R.S.M., F.G.S., P. N. DATTA, B.SC. (LONDON), F.G.S., AND E. VREDENBURG, B.L., B.SC. (PARIS), A.R.C.S.

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GEOLOGY OF THE SON VALLEY IN THE REWAH STATE AND OF PARTS OF THE ADJOINING DISTRICTS OF JABALPUR AND MIRZAPUR, *by* R. D. OLDHAM, *Superintendent, Geological Survey of India,* P. N. DATTA, *Deputy Superintendent, Geological Survey of India,* AND E. VREDENBURG, *Assistant Superintendent, Geological Survey of India.*

CHAPTER I.—INTRODUCTION.

(R. D. OLDHAM.)

Area dealt with.

The area with which the following report is primarily concerned is that portion of Rewah territory which lies south of the Kaimur scarp, forming a strip of ground about 25 miles broad, and bounded by the British districts of Jabalpur and Mirzapur on the west and east respectively. Some references to it will be found in Mr. Mallet's Vindhyan Memoir, but these were based solely on two rapid traverses by Mr. H. B. Medlicott from east to west of the tract comprised in Rewah territory.

History of the survey.

Of the country east and west of Rewah there are old surveys, made by various members of the Geological Survey previous to 1873, but the survey of the part comprised in the Rewah State was first undertaken in 1893 by Mr. T. H. Hughes. Owing to other demands on the survey a number of different officers have been detailed for work in Rewah,

and the resulting memoir suffers from the drawback of being a compilation from the work of a number of men who have each surveyed different portions of the area. In 1894 the survey having been put into my charge, I had not only to re-survey a portion of the area, but also made several tours of the region for the express purpose of linking up, so far as possible, the work of other officers of the survey.

On the map accompanying this memoir the geology of the part comprised in Rewah State is exclusively based on the recent surveys. In Mirzapur the boundary of the lower Vindhyans was re-surveyed by Mr. Vredenburg in 1895-96, but with this exception, and some modifications mentioned in the text, the geological outlines are taken from the old surveys. West of Rewah the country has not been revisited and the old surveys have been incorporated. Very little reference will be found in the following pages to the area covered by the map outside Rewah State, but its incorporation in the map was considered advisable in order to complete the geological features which would have been but imperfectly exhibited if the map had been strictly confined to Rewah territory.

Previous accounts.

Of previous published accounts of this area there are very few. For the earlier ones reference may be made to Mr. Mallet's memoir [1] published in 1869. Since that date the only published statements regarding the region dealt with in this memoir are to be found in the Records of the Geological Survey of India.

An analysis of Galena,[2] a description by Mr. T. H. Holland of some rocks collected by Mr. P. N. Bose [3] and three analyses of iron ore [4] are printed in the lists of assays and examinations made in the laboratory of the Geological Survey. Some specimens of norites from this area are described in a paper by the same author in Vol. XXX. of the Records, Geological Survey of India, pp. 16-42.

[1] Mem., Geol. Surv. Ind., Vol VII., pt. i.
[2] Rec., Geol. Surv. Ind., Vol XXVI., p. 109.
[3] Rec., Geol. Surv. Ind., Vol XXVII., p. 149.
[4] Rec., Geol. Surv. Ind., Vol XXX., p. 256.

Besides these there are two papers in Vol. XXVIII. of the Records and one in Vol. XXIX., which have been incorporated in the following memoir.

Authorship of the memoir.

The authorship, and more particularly the authority, of the following memoir is necessarily composite. Where possible the authority for the statements made is given, and in the case of the chapters written by Mr. P. N. Datta and Mr. E. Vredenburg both authorship and authority are exclusively theirs. The rest of the memoir has been compiled by myself and is based on the reports and surveys of the following officers of the Department, namely, J. G. Medlicott, H. B. Medlicott, W. L. Wilson, F. R. Mallet, C. A. Hacket, T. W. H. Hughes, H. Kane, T. H. Holland, P. N. Bose, F. H. Smith, G. E. Grimes and Kishen Singh. In cases where more than one officer has visited a place it has not been possible in every case to quote the authority for a statement which may be a combination of the work of more than one person. As a general rule it may be taken that statements made without qualification are the result of my observations, or have been verified by me; where they are made entirely at second hand the name of the authority on which they are made is always given.

CHAPTER II.—STRATIGRAPHY.

(R. D. OLDHAM.)

Transitions: Bijawar series.

The oldest rocks in the area under description belong to that complex of unfossiliferous and more or less metamorphosed rocks to which the name transition is applied for want of a better one, and of these by far the greatest portion may be ascribed to a series of slates or schists, associated with volcanic beds and jaspers which resemble in general type the Bijawar series of Bundelkhand. The petrology of these rocks of Bijawar type, or rather of the more peculiar members of the series, has been studied by Mr. Vredenburg, whose description is printed in Chapter IV of this memoir.

Newer conglomerates.

Besides the Bijawar series, as it may be termed, there is at least one series of later age included in the area coloured as transition. The distribution of these rocks could not be worked out, the area they cover seems comparatively small, but their distinctness is conclusively proved by the occurrence of pebbles of Bijawar jasper, and especially of the very conspicuous and easily recognisable red jasper of that series, in the basal conglomerate of the newer series.

The principal exposure of these rocks is between Long. 82° and 82° 30′ E., where they occur immediately south of the narrow strip of newer rocks. Other exposures are known, but it was not found possible to map them as a distinct series owing to the difficulty of separating any but the basement beds from the older transitions. It is in fact somewhat doubtful whether they should not be classed rather with the newer series of sedimentary rocks which will be described later on, but the difficulty of separating them from the transitions, as compared with the comparatively well-marked distinctness of the newer series, has influenced the decision, and they are treated, as they were necessarily mapped, as belonging to the transitions.

Relation to granitic intrusions.

The relation of these newer transitions to the granitic intrusions has not been made out as they have not been found in contact with each other, but with this possible exception that the newer transitions

may be of later date, the next succeeding formation, in point of age, is the intrusive granite. This, as will be seen from the map, is found in two main exposures, respectively north and south of the transition area, and bounded on their north and south margins by newer rocks: Vindhyans to the north and Gondwanas to the south.

Of the relation of the crystallines to these newer sedimentary formations there is no doubt, in both cases there is a marked unconformity, the crystallines having been uplifted, denuded and then covered by newer deposits. The junction of the crystallines with the transition rocks is less definite and even open to the possibility of more than one interpretation.

Along the whole of the junction of the transition and granitic rocks there is a band, sometimes reaching two or three miles in width, where the gneissose and schistose rocks occur intermixed, and in the few sections exposed in stream-beds the gneiss is seen to occur in veins or bands running more or less parallel with the foliation of the schists. Sections of this nature were at one time held to indicate an interbedding of gneiss and schist and to prove the conformity of the two series; the interpretation is not, however, now in favour, and in the area under description there are, in spite of the imperfection of the contact sections, indications that this is not the true interpretation.

Contact metamorphism.

In the first place there is the evidence of contact metamorphism Not only do the transition slates become distinctly more schistose as the granitic masses are approached, but in the sections occasionally seen in stream-beds, it is seen that the schistosity often increases markedly in the immediate neighbourhood of the gneissose bands, indicating that the latter had been injected in a heated condition and caused a certain amount of local change in the rocks they invaded. Secondly, it is seen, in these sections, that the gneissose bands do not invariably follow the foliation of the transitions, but occasionally cut across it; the foliation having in this case been developed parallel with the bedding planes. Thirdly, inclusions of schist are found in the bands of gneiss.

Sill structure.

All these facts point to the conclusion that the thin bands of gneiss are in reality intrusive sheets, emanating from the main granitic mass, which have taken on a foliated structure like the thin sheets of the so-called "central gneiss" in the Himalayas. The intercalation of the gneiss and schists is in fact a case of what Professor Edgeworth David has called "sill structure."

Lithology.

Comparatively little attention was paid to the lithology of the gneissose and granitic rocks. On account of the comparative rapidity of their decomposition they occupy low ground, round which the harder rocks of the transitions stand up in hills; in consequence of this depression of the surface it is largely covered with recent deposits, and the rocks very ill exposed, except occasionally in the stream-beds. The rock is generally a massive crystalline gneiss, in which the foliation is often so indistinct that it becomes unrecognisable in hand-specimens. At times the rock is porphyritic with orthoclase crystals running to a couple of inches in length and scattered irregularly through the rock with their longer axes at all angles with the foliation planes.

The massive forms are usually found in the main exposures, and the more foliated forms near their boundaries and in the thin sheets penetrating the transitions.

Associated with the gneiss are veins of aplite, composed of quartz and pink felspar, which often becomes a graphic granite. Quartz-veins are common, and there are numerous intrusive dykes of dark-coloured aphanite and hornblendic trap which become amphibolite in many cases; unaltered cores of augite in the centre of the hornblende crystals show this to be an altered pyroxenite.

An intrusion worthy of special note is one of a coarse-grained olivine-norite, in the bed of the Son near Kaithaha. It consists of apatite, olivine, enstatite and augite, biotite, plagioclase, with actinolite and enstatite, biotite and magnetite occurring as secondary minerals. This rock which has been described by Mr. Holland[1]

[1] Rec., Geol. Surv. Ind., Vol. XXX., pp. 20-21 (1897).

is principally remarkable for the conspicuous "reaction rims" surrounding the olivine crystals.

Between the intrusion of the granite and the formation of the next successive sedimentary series ensued a long period, possibly bridged over in part by the later conglomerates mapped as transitions, though, as has been pointed out, there is no evidence of their age relative to the granites. During this period there was evidently a good deal of disturbance of the beds, as is evidenced by the strong divergence of dip between the Bijawar and the unconformable lower Vindhyan beds on some sections, and one of the leading structural features of the region was marked out.

Interval succeeding the granitic intrusions.

It will be noticed that the crystalline rocks are exposed in two areas respectively north and south of the band of transition rocks, and as the former must have consolidated at a considerable depth below the surface, this implies a greater structural elevation of the areas they now occupy than of the intervening belt. In other words, the transition rocks lie in a great synclinal depression or synclinorium, and the fact that the crystallines are unconformably covered by the lower Vindhyans shows that they must have been raised and laid bare by denudation even at the early period of the commencement of the Vindhyan epoch.

Zone of depression.

The synclinal depression formed at that period was continued and increased during succeeding geological ages, as is shown by the line of outlines of newer rocks which runs through the transition area. The axis of elevation lying north of this line is continued into the Vindhyan rocks towards Sarsi on the one hand and Bijaigarh on the other, and, as will be shown later on, was apparently marked by an actual elevation of the surface level even in lower Vindhyan times.

Following on that undefined collection of more or less metamorphosed sedimentary series, which is classed as transition, comes the oldest which can be

Jungel or Red Shale series.

recognised and mapped as a separate series. Its individuality was first recognised in 1894-95, previous observers having classed the beds of this series with the transitions or, in places, with the lower Vindhyans. No complete section of the series is seen anywhere, and it is consequently difficult to select a local name for the series; if any be adopted it should be taken from the village of Jungel (Joongeyl) on the borders of the Mirzapur district, near to which is an extensive exposure and a very complete section. In view, however, of the fragmentary nature of the exposures and the probably local distribution of the series, I do not propose to adopt a geographical name, but to distinguish it as the "Red shale series" from the prevailing rock of which it is composed.

Distribution.

The distribution of the exposures of this series is peculiar. It occurs as a series of narrow outliers, running about east-north-east which all occupy synclinal basins, though the synclinal is usually faulted on one side. At the extreme western end of the zone of depression running through the area of older rocks, and where its axis sinks under the great spread of lower Vindhyans west of the Kharara hill, there is a small exposure of the red shale series unconformably overlaid by the lower Vindhyans of the main exposure. With this exception the red shale series is nowhere in normal, and only for a short distance near Marai in faulted, contact with the main exposure of the lower Vindhyans. Elsewhere the exposures are usually bounded by older rocks, but in places the rocks of the red shale series are overlaid by newer beds of the outliers of the Vindhyan system.

Original extent.

From this it will be seen that there are no indications of the original extension of this series. At present its exposures are strictly confined to the zone of depression referred to above. The disturbance of the beds is, however, great in all the exposures and the outcrops now seen are evidently but the remnants of a once much more extensive series of beds. This may possibly have extended northwards under the area now occupied by the Vindhyan system, but if so it is strange that

there is no remnant of them to be found along the whole length of the boundary between Marai and Chopan.

Subdivision into stages.

In the western exposures the section is very incomplete, the greater part of the series having been removed by denudation previous to the deposition of the lower Vindhyan strata; in the eastern exposures, where the section is more complete, the series is divided into three principal stages:—

(3) Lower, sandstones and conglomerates.

(2) Middle, shales.

(1) Upper, sandstones or quartzites.

The divisions between these stages are not well marked, and rocks of both types are found in every stage, though the prevailing facies is, as indicated by the nomenclature, that of fine-grained beds in the middle and coarser ones above and below. Conglomerates are confined to the base of the series.

Lower stage.

The lower stage varies in thickness from 15 or 20 feet to 500 feet, the variations being in part due to the horizontal replacement of the sandstones near its upper limit by shales, but principally to inequalities of the surface on which it was deposited. Near the base of the series, but not as a rule forming the lowest bed, a conglomerate is a frequent member of the series, and is usually thickest on those sections where the lowest stage attains its greatest thickness.

Conglomerates, in the true sense of the word, are, however, of somewhat rare occurrence in the series, and usually of small thickness. Pebbles, on the contrary, are very abundant in the sandstones of the lower stage, usually tolerably well or perfectly rounded, of small size, as a rule not exceeding two inches but occasionally ranging to six inches in diameter. These pebbles are found scattered through a sandy matrix in varying proportions, usually they are separated from each other by several inches or feet of matrix, but may occur in increasing proportion, till the rock finally passes into a true conglomerate.

A rock of the character of that just described is essentially and inevitably of subærial origin. The peculiar mixture of pebbles with fine sand is impossible as a subaqueous deposit, for the current capable of moving the one would sweep away the other. In the case of a stream flowing on the surface of the land different conditions prevail; there is at every point a certain level, determined by the conditions of the stream, below which it cannot erode. Pebbles may consequently be swept over a surface of sand, which the current is unable to attack because it lies at too low a level, and subsequently become covered by a fresh accumulation of sand. The frequent occurrence of current bedding in the sandstones, and the manner in which shale beds give way laterally and vertically to beds of sandstone, all point to the same conclusion, that these deposits were formed subærially by streams flowing over the surface of dry land.

Subærial origin.

The arenaceous lower stage passes upwards into the argillaceous middle stage. The rocks composing this are mostly shaly, though sandstones also occur; the prevailing colour is red varying from dull brick to bright vermilion, as a rule pure and free from any tendency towards violet. As is common in red rocks a pale green colour is common occurring as a mottling or in patches of larger size, the boundaries between the two colours being quite independent of the bedding planes. In the eastern exposures, where the sections are most complete, some pale grey shales are found near the top of this stage.

Middle stage.

The upper sandstones are only well seen in the two easternmost exposures, they resemble those of the basal stage, being white, much false-bedded and, in the Jungel outlier, containing scattered pebbles.

Upper stage.

The thickness of the series as a whole varies much in different exposures the greatest being seen in the most easterly, where it is estimated by Mr. Vredenburg at about 1,500 feet, and as an unknown thickness of beds, above the uppermost seen, has been remeved by denudation, the original

Variations of thickness.

thickness must have been greater than this. The thickness seen in the other exposures varies greatly and is always less than this, the difference being in part due to the removal of the upper beds by denudation. It is probable, in a series formed as this has, that there were great original variations in the total thickness, as there certainly are in the thicknesses of the individual stages.

The basal stage, as has already been mentioned, varies from 20 to 500 feet within short distances. The middle stage too is subject to great variations, the most striking case being near Ghurder. In the scarp above that village there are only some 10 or 12 feet of shale, representing the middle stage, the rest of the series being entirely composed of sandstones; about a mile to the north of this scarp the shales have thickened to several hundred feet, but it is uncertain how far this is a real thickening of the stage or due to horizontal replacement of the sandstones by shales.

The upper stage of sandstones is only represented in the two easternmost exposures, and most conspicuously in that furthest east. Near Ghurder it attains a thickness of about 300 feet and in the Jungel outcrop there would seem to be at least 1,000 feet exposed, according to Mr. Vredenburg.

Vindhyan system.

Following on the red shales in ascending order come the rocks of the great Vindhyan system. These are divided into upper and lower, the former consisting of three divisions to which, on account of their thickness, the word series might not inappropriately be applied, though throughout the three there is a prevailing uniformity of character which unites them in one great series of sandstones with subsidiary zones of shales or limestone. The lower Vindhyans, on the other hand, are sharply distinguished from the upper by the prevailing rocks being shale or limestone, sandstones forming but a small proportion of the total thickness, and being usually more earthy and impure than those of the upper Vindhyans.

Lower Vindhyan series.

The subdivision of the lower Vindhyan series which is best known is that of Mr. Mallet, published in his memoir "On the Vindhyan series in the North-

Western and Central Provinces", and repeated in the two editions of the Manual of the Geology of India. Mr. Mallet's zones are as follows [1]:—

11. Limestone.
10. Shales.
9. Limestone.
8. Shales, sandstone.
7. Limestone.
6. Shaly sandstone.
5. Porcellanic shales.
4. Trappoid beds.
3. Porcellanic shales.
2. Limestone.
1. Conglomeritic and calcareous sandstone.

Subdivision into stages.

This classification was formed in the eastern part of the Son valley exposure of lower Vindhyans, beyond the limit of the map attached to this memoir, and in that area all the eleven zones can be readily recognized. In the western area it was found that though the sequence on the whole resembled that described by Mr. Mallet, the individual zones could not be recognized with certainty and a more generalized classification was adopted as follows:—

4. Rohtas stage.
3. Kheinjua stage.
2. Porcellanite stage.
1. Basal stage.

Of these the lowest includes Mr. Mallet's Nos. 1 and 2, the Porcellanite stage his 3, 4, and 5, the Kheinjua stage, his Nos. 6, 7, and 8, and the Rohtas stage Nos. 9, 10, and 11.

It must, however, be borne in mind that these stages are not separated from each other by well-defined horizons. They merely represent different facies of deposits which pass into each other,

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 28.

and it is more than probable that the boundaries as mapped do not represent isochronic divisions. That is to say, beds which in one section have, on account of their lithological character, been mapped in one stage may be contemporaneous with beds that have, in other sections, been mapped with those of a contiguous stage.

Basal stage.

The lowest of these is that which has been called basal. It consists of sandstone and conglomerate at the bottom, overlaid by a varying thickness of shales and limestone. Of all the stages it shows the greatest and most rapid variations in thickness, and this is especially prominent in the lowest beds of all. These usually consist of sandstones and pebbly sandstones of the same type and character as those at the base of the red shale series, and were evidently formed in a similar manner. On some sections these rocks attain a thickness of four or five hundred feet and then form a conspicuous ridge, such as that which marks the boundary of the lower Vindhyans from Marai to the neighbourhood of Samaria. In the eastern outlier, near Tarka, the conglomerate is replaced by an angular breccia, which is evidently an old talus deposit, the disintegrated rock on and at the foot of the old hill-sides having been covered up by subsequently added deposits without having been washed away or sorted by stream action.

Above the sandstone there comes, at the eastern end of the area on the map, a massive limestone which attains a thickness of some 300 to 400 feet about Agori. In the central and western parts of the area a band of limestone sometimes overlies the sandstone and at places there are thin strings of siliceous limestone in the sandstone, but as a rule the rock immediately above the basement beds is a fine-grained shale, often as fine-grained and soft as is to be found anywhere in the whole thickness of the lower Vindhyans.

These shales are capped, in the neighbourhood of Marai and Deora, by a conspicuous band of limestone, which is cut off by a fault to the west and disappears by thinning out to the east.

The thickness of the stage as a whole varies no less than that of the basement sandstones and conglomerates and as a rule in the same direction. That is, on those sections where the basement beds are thickest, the overlying shales and limestone are also at their thickest ; while on those sections where the coarse-grained basement beds are reduced to a few feet the overlying shales are also thin, and the porcellanites are brought close down to the boundary.

Porcellanite stage.

For the porcellanite stage I have retained the name originally applied to these beds, though their true nature has now been fully established by Mr. Vredenburg's careful study of their petrology which forms Chapter V of this memoir.

The typical rock of the stage is a hard fine-grained porcellanic rock, varying in colour from almost black to a pale green, compact, and breaking with a conchoidal fracture. It forms extremely sharp-edged splinters, so keen that I have seldom obtained a specimen without receiving one or more cuts from the flying chips. This feature, combined with its evenness of grain, made it a favourite material with the men of the stone age in this region for the manufacture of stone implements, both large sized axes and choppers and small flakes, of which many singularly perfect specimens were found.

Associated with these fine-grained rocks are others to which small fragments of quartz and felspar give a porphyritic aspect, and in places these fragments become so numerous that the rock assumes the form described by Mr. Mallet as trappoid. In the western area, where these rocks are most developed, hornblende is a much less common ingredient than in the similar rock east of the Mirzapur district to which Mr. Mallet's description [1] more especially applies.

The thickness of this stage near the western boundary of the Rewah State cannot be less than 800 feet, but the boundaries are very uncertain. Rocks of very similar type are found interbedded among the lower Vindhyans both above and below that portion which

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 36.

has been specifically separated as the porcellanite stage owing to the marked prevalence of the harder beds.

When well developed and well exposed the outcrop of this stage forms a band of low hills, covered with a forest of *salai* trees (*Boswellia thurifera*) and the surface in detail is also very characteristic, owing to the interbedding of soft shales with the hard beds, which are traversed by numerous joint planes running through the bed at right angles to the bedding, most of them not continuing into the beds above and below.

Distribution.

The distribution of the rocks of this stage is peculiar. Near the western limit of the Rewah State they attain, as has been mentioned, a thickness of not less than 800 feet, and here the coarse-grained beds, containing an abundance of felspar and quartz, are largely developed. Passing eastwards the thickness diminishes somewhat and the porphyritic-looking beds gradually disappear, being seldom seen east of 81° 30′ Long. From here on to the Gopat the outcrop is still easily traced though the beds are thinning, and beyond the Gopat the thinning is very marked. The last good exposure near Pari shows only fine-grained beds associated with shales and not more than about 200 feet in total thickness. A small exposure is seen on the south bank of the Son east of Gangi, but the outcrop of the rocks of this stage south of Hurma is hidden by the Son.

East of Khattai exposures of rock are few and far between; some beds of a porcellanite rock are seen and the porcellanites are represented by some very rare angular fragments in the subrecent river gravels. At Gurdah the porcellanites are not seen, being apparently cut out by a strike fault, but a short distance to the east they reappear and can be traced to and beyond the limits of the map. In this direction, too, they thicken out and at the same time the coarser-grained reappear, and east of Kon, beyond the limit of the map attached to this memoir, there is evidently a development of these beds comparable to that on the western border of Rewah.

The thinning out of the porcellanites from a maximum development at either extremity of the map to a disappearance in the stretch between Hurma and Gurdah is for two reasons less conspicuous in the map than it otherwise might be. In the first place, the apparent thinning out of the rocks of this stage may be due not to an actual thinning of the beds of the same age as the porcellanites at either extremity of the area included in the map, but to a disappearance of the hard beds and a corresponding increase of the intercalated shales which cannot be separated from those of the under and overlying stages. Consequently when the hard rocks cease to be present in sufficient proportion to give a special character to the stage and enable it to stand out by its superior resistance to denudation, there is an appearance of comparatively sudden extinction of the stage. In the second place, the wide expanse mapped as porcellanites west of Markundi is due to an expansion of the outcrop owing to its being exposed along the crest of a very open anticlinal, while the other wide expanse west of the Gopat is due to the fact that the portion of this area lying north of Lat. 24° 30′ was surveyed by Mr. Datta, who has included and placed the upper limit of this stage at a higher horizon than that adopted by Mr. Grimes and myself in the country south of this parallel. Where the boundaries between the stages are so indefinite as in the lower Vindhyans, and where the division between one stage and another depends on whether a certain form of rock may be regarded as the characteristic or merely as adventitious, such differences between different observers is inevitable, and will also be found in the mapping of the same observer in different areas.

The complete disappearance of the stage between Hurma and Gurdah is largely a matter of cartographical convenience. The exposures here are too few to allow of its presence or absence being definitely established, but it is difficult to believe that, if the porcellanites were present in anything like the development they attain to the east and west of these limits, there could be a complete absence over so large an area of any outcrop of a stage which, through its hardness,

generally rises into hills. Mr. Vredenburg has suggested that the absence of outcrops may be due not to a disappearance of the porcellanites, but to their outcrop being in the ground covered by the bed of the Son and therefore hidden.

It is true that the outcrop of the rocks of the horizon occupied elsewhere by the porcellanites runs under the bed of the Son at Hurma and again from about Silpi to Gurdah, but between these points there is a stretch of about 25 miles where it must run over the ground south of the S n, yet throughout this extent no exposures can be seen. When we r ollect that sewhere the rocks of this stage almost invariably rise to ranges of hills it is difficult to account for the complete absence of an outcrop of the stage as a whole without supposing that it has either thinned out, or that the characteristic hard beds have become so few and small in comparison with the softer interbedded shales that the stage as a whole has no longer the power of resistance which it elsewhere possesses. In either case there is a marked diminution of the amount of foreign material introduced among the purely aqueous deposits which may be considered as a thinning out of the volcanic ashes of the porcellanite stage.

Centres of volcanic eruption.

From the above it will be seen that the rocks of this stage have their maximum development near the western and beyond the eastern limit of the area included in the map. Further the regions of maximum thickness are also those of the greatest development of the coarse-grained beds. These two facts taken together point to an approach, in either direction, to the centres of volcanic activity from which these ashes were ejected.

It is not possible to say whether these centres lay to the south of the present lower Vindhyan boundary or to the northwards under the country now covered by the Vindhyans. The fact that the exposures of the porcellanite stage in the outliers seem to be less in thickness and on the average finer in grain than in the corresponding parts of the main area to the north is, to a certain extent, an indication that the volcanic centres lay in that direction rather to the south.

The name of the Kheinjua stage is derived from a range of hills lying south of the Kaimur scarp at and beyond the western boundary of the Rewah State in the Son valley. It appears to have been first used on the field maps of Mr. W. L. Willson in 1872, but the first published appearance of the name was in 1895.[1]

Kheinjua stage.

The area occupied by the rocks of the Kheinjua stage was surveyed by Mr. Datta who has written the detailed description of the subdivisions of this stage printed as Chapter IX of this memoir. The remarks on the lithology of the rocks of this stage will consequently be restricted to generalities.

The rocks of the Kheinjua stage are principally shales and sandstones. Some of the latter are purely arenaceous and sometimes indurated to form quartzites ; but as a rule the sandstones are impure, divided into thin beds, and freely ripple-marked on the bedding surfaces. Limestones occur occasionally, and at the western limit of the map there are three thick bands which thin out east of Ramnagar and cease to be traceable as continuous bands.

From near Ramnagar, eastwards to the neighbourhood of Markundi, occasional outcrops of limestone are found, and the bands may sometimes be traced for a few miles, but there is no development of limestone comparable to that west of Ramnagar. East of Markundi and Chopan limestone again becomes a conspicuous member of the stage, and Mr. Mallet's No. 7 attains a thickness of 200 to 300 feet.

The uppermost member of the stage is a set of beds of shale through which large rounded black calcareous concretions are scattered. On the freshly fractured surface they appear to be compact and homogeneous, except for traces of the original bedding traversing them at right angles to their shorter axis. When weathered, however, a series of furrows radiating from the centre indicate an invisible septarian structure of radiating fissures, too fine and close to be visible or to affect the fracture of the stone, but offering planes of more ready solution of the material composing the nodules. These

[1] Rec., Geol. Surv. Ind., Vol. XXVIII., p. 145.

furrows are not confined to the upper rounded surface of the nodules, where they might be explained by a radial shedding of the rainwater, but are also found on fractured surfaces where these have been exposed to the weather for a sufficient period of time.

Conditions of deposition.

The conditions of deposition of the rocks of the Kheinjua stage seem to involve an alternation of subaqueous deposit in shallow water and subærial accumulation. The frequent ripple-markings may be due to the action of either wind or water in motion, but the suncracks and raindrop marks prove that the surface of the beds on which they are found was exposed to the air and not covered by water. The conditions are in fact those of extensive mud flats which, in the course of the period covered by the formation of this stage, were sometimes converted into shallow lakes, and sometimes exposed as mud flats on which the material washed down from the neighbouring high ground was slowly accumulated.

The limestones have all the appearance of a subaqueous deposit. It is difficult to see how regularly bedded limestones could be otherwise formed, though it is also remarkable that neither in the limestones nor in the associated shales has any trace of living organism been found.

It is a noteworthy fact that these limestones, which suggest, though they do not necessitate, tolerably deep water conditions of deposition, are absent or very little developed opposite the strip of older rocks cut off by the line of Vindhyan outliers while they are well developed on either side. This indicates that the region of structural elevation lying between the main area of the Vindhyans and the band of outliers, was even in lower Vindhyan times not only a region of special structural elevation, but also a region of greater surface elevation, over which the comparatively deep water conditions to east and west were replaced by shallow water or dry land.

Rohtas stage.

The name of Rohtas was first[1] proposed by Mr. Medlicott in 1879 for the group of limestones and associated shales at the top of the lower Vindhyans. The

[1] Manual of the Geology of India, 1st Ed., p. 78.

most typical member of it is a thin bedded flaggy limestone, which passes by insensible gradation into the uppermost beds of the Kheinjua stage. In the east a well-marked band of shales, some 300 feet thick, is found above the principal zone of limestones and in places in direct contact with the Kaimur sandstone. In the west this shale band is not found, and the predominant rock throughout is limestone, with a small thickness of shales above. In the central portion of the area the exposures are too scanty to allow of the presence of a thick band of shales being affirmed or denied.

The lithology of the rocks composing this stage is very constant, and has already been described by Mr. Mallet[1] and by Mr. Datta (see Chapter XI), and need not further be referred to here; but a very remarkable set of shaly beds, occurring at the top of the Rohtas stage and immediately underlying the Kaimur sandstone, must be referred to. The greater part of these shales are argillaceous, but towards the top they become siliceous, hard, and porcellanic in appearance on the fractured surface. The most peculiar of these, and the uppermost, is a pale coloured or white, hard, siliceous rock splitting into laminæ or layers of varying thickness, the planes of separation being coated by a thin layer of red ferruginous material. The rock itself breaks with a conchoidal fracture, is compact, and presents an appearance on the broken surface not unlike that of a Wedgewood mortar.

These beds are seen at intervals from the western limit of the map to about Long. 82° E. From here there is a long stretch where the base of the Kaimur sandstone is not exposed, but near Hurma, where the contact once more rises above the recent deposits, the hard siliceous shale is not seen. In the Mirzapur district a similar rock is seen, but interbedded in the Kaimurs. On the Silpi Ghat the horizon was above the Bijaigarh shales, further east, about Markundi, they were found interbedded with the lower Kaimur sandstone.

[1] Mem., Geol. Surv. Ind., Vol. VII., pp. 41 ff.

From this it would seem that, though a rock similar to the hard pale-coloured siliceous rock of the west is to be found east of Bardi, it does not show the same constancy of horizon and cannot be safely correlated with that which for a distance of some 80 miles is found separating the Kaimur sandstones from the limestones of the Rohtas stage.

Variation in thickness.

The thickness of the beds attributed to this stage varies largely, notwithstanding the statement in Mr. Mallet's memoir [1] to the contrary. It must be remembered that these statements were based on a survey of the country east of the map accompanying this memoir and of the country west of Rewah, the intermediate country being practically unknown, and as regards these areas the statement is substantially correct.

The greatest thickness is attained near the western limit of Rewah territory. Here there cannot be less than 1,000 feet of beds belonging to this stage, while the actual thickness is probably over 1,500 feet. In an easterly direction the stage maintains a considerable thickness, and though there is a narrowing of the outcrop as mapped, no great importance can be attached to this on account of the impossibility of determining the exact position of its southern boundary.

At Hurma, where the lower boundary can once more be seen, it has fallen much in thickness, but east of this the Kaimur boundary recedes northwards, away from the southern limit of the lower Vindhyans, and the Rohtas outcrop widens once more, probably in unison with an increase of thickness.

Near Gurdah there is not more than 150 feet of the limestones actually seen, though the total thickness may be more, and near Markundi the thickness reaches its minimum. In the Ghagar not more than 50 feet of bedded limestones separate the Kaimur sandstone from the shales with calcareous concretions, and this thickness only increases to not much over 100 feet about Rudauli. There

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 47.

is here some uncertainty as to the thickness of beds which should be ascribed to the Rohtas stage on account of the unusual development of the nodular shales, the number of the calcareous nodules, and the occurrence of more or less impure calcareous bands among the shales. The bottommost beds of the Rohtas stage contain bands of shale with calcareous concretions, very similar to those at the top of the Kheinjua stage, so that it is difficult to draw the boundary here. Still, unless the limestones in the Ghagar at Markundi are Rohtas and not Mr. Mallet's No. 7, it is evident that the thickness of the Rohtas stage must be very much less here than further to the west. South of the Kaimur scarp, where it resumes its general easterly course, the thickness of the Rohtas stage is not less than 700 feet and it seems to preserve this or a greater thickness to the east.

Cause of variations.

These variations may be ascribed in part to original variations in the thickness of the deposits, in part possibly to removal of some of the upper beds by denudation, prior to the deposition of the Kaimur sandstone, but are also explicable in part by the fact that the base of the stage is not a well-marked horizon, but is drawn where the deposits change from an argillaceous to a calcareous character. This may well have taken place at different times on different sections, and the base of the stage as mapped at one place probably represents a higher or lower horizon than it does at other places.

Though doubtless a partial cause of the variations in thickness of the Rohtas stage, the last-mentioned explanation is not sufficient to account in full for the variations. These can only be satisfactorily dealt with in connection with the distribution of the rocks of the upper Vindhyans, and their consideration must consequently be deferred. It may, however, be noted that on the whole the thickness of both Kheinjua and Rohtas stages is greatest where the distance between the boundary of the Kaimurs and the southern boundary of the lower Vindhyans is greatest, and least where they approach most closely to each other. The one striking apparent exception to this

is in the small development of the limestones of the Rohtas stage near Markundi, but in this case it must be remembered that the distance is measured along, while elsewhere it is measured across, the strike, and the cases are consequently not strictly comparable.

Upper Vindhyan series.

The rocks of the upper Vindhyans in the main area of their exposure were not specially examined during the late survey, and so far as they are concerned there is nothing to add to the statements in Mr. Mallet's memoir. A few outliers north of the Son present no special features of interest, the type of rock and the relation to the lower Vindhyans is the same as in the adjacent Kaimur scarp.

Outliers south of the Son.

South of the Son, however, there are a series of outliers which cannot be ascribed to any other age than upper Vindhyan. Omitting small outliers there are three principal ones which occur along the zone of structural depression already referred to. In each case the outlier occupies high ground and is usually scarped round its edge, owing to the resisting power of the rocks of which it is composed, as compared with the more readily decomposed schists on which it rests. The rock differs considerably from that of the Kaimur or any of the overlying series of the upper Vindhyans in that it frequently contains pebbles and even boulders of a foot in diameter, composed of quartz or jasper. In some places the abundance of red jasper pebbles derived from the Bijawars gives it an appearance very like that of the Kaimur conglomerate as described by Mr. Medlicott.[1]

The sandstones of the upper Vindhyans, on the other hand, are remarkable for the absence of pebbles. Mr. Mallet records the occurrence of pebbles at the base of the Kaimur sandstone near Badanpur,[2] and to the east in Mirzapur, fragments of chert, apparently derived from the lower Vindhyans, are found in the lower sandstone of the Kaimur stage. With these exceptions not a single pebble or fragment of larger size than can be described as coarse sand

[1] Mem., Geol. Surv. Ind., Vol. II., p. 28.
[2] Mem., Geol. Surv. Ind., Vol. VII., p. 55.

has been seen in the upper Vindhyans of Rewah by any of the observers who have examined them, and this in spite of the fact that in at least one instance special attention has been devoted to this point.

In spite, however, of this difference, and in spite of the close resemblance of the rocks of the outliers to those of the basal beds of the lower Vindhyans and of the red shale series, there is little room to doubt that they represent some part of the upper Vindhyans. The evidence that they are newer than the lower Vindhyans is, in one case at least, indisputable, and the only other system newer than the lower Vindhyans known in this neighbourhood is the Gondwana. Unless then, which is highly improbable, they represent the remains of some system intermediate in age between the Vindhyan and Gondwana, they must belong to one or other of these two. From the Gondwanas they are distinguished by their greater degree of induration, and of disturbance, as well as by the distance they are removed from the present boundary of the Gondwana exposure, which there is good reason to suppose represents very closely the original limit of their formation. They are besides certainly older than the upper Gondwanas of this region, for these have been recognized in one place (see Chapter VI) to contain *débris* of the rocks composing the outliers.

There remains but the upper Vindhyan system to which the outliers can be referred. The degree of induration is such as would be expected in rocks of this age, and though the disturbance is somewhat greater than that of the main area of upper Vindhyans, they may safely be ascribed to this age, the presence of pebbles being ascribable to a greater proximity to the original limit of the area of deposition.

Relation to lower Vindhyans in the outliers.

Though almost certainly of upper Vindhyan age, the rocks of these outliers exhibit a marked difference in their relation to the lower Vindhyans from those of the main area. In one case, the Kharara outlier, they are found resting in complete unconformity on the eroded edges of the nearly

vertical beds of the lower Vindhyan series; in the other outliers this direct evidence is not available, but the manner of their occurrence shows that their deposition was posterior to the greater part of the disturbance now shown by the lower Vindhyans, and to an extensive denudation of these and the older rocks.

and in the main area.

In contrast to this, we find along the boundary of the main area either direct indications of a conformity between the lower and upper Vindhyans or very doubtful indications of a slight unconformity. On the north side of the Vindhyan plateau Mr. Mallet's description [1] leaves no possibility for doubting the perfect conformity of the Rohtas and Kaimur stages, at any rate in the Durgauti valley. In the Son valley the sections are less clear, but west of Long. 82°E. the constant occurrence of a peculiar and easily recognizable band of siliceous shales, and the existence of sections showing a passage of these into the Kaimur sandstone above and the shales and limestones of the Rohtas below, indicate a conformity between the two stages. Further east we have a long stretch where no sections are seen, but at Hurma the junction is once more seen and from here eastwards to Markundi, though numerous sections have been seen, there is no trace of the peculiar siliceous shales seen further west. It is near Markundi that, as already mentioned, the beds recognized as belonging to the Rohtas stage are at their thinnest, and this might be held to indicate erosion previous to the deposition of the Kaimur sandstones.

Possible replacement of Rohtas by sandstone.

Against this supposition must be placed the fact that the few sections which show an actual contact between the beds of the two stages, though they show an abrupt change from the argillaceous and calcareous beds of the Rohtas to the arenaceous deposits of the lower Kaimur, show no signs of erosion. It must also be remembered that it is just in this area where the lower Kaimur sandstone attains its maximum thickness and it is not an impossible supposition that this may represent a part of the deposits which elsewhere are classed with

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 46.

the Rohtas on account of their lithological composition. The coincidence of a thinning out in either direction of the lower Kaimur sandstone with a thickening of the Rohtas beds may be held to favour the supposition, and in further support of it there is the presence, both on the Hurma section and near Markundi, of a band of sandstone in the Rohtas beds, which closely resembles that of the Kaimurs.

Lower Vindhyan *débris.*

Whether there is any truth in the suggestion hazarded in the last paragraph or not, it may be taken that there is no direct evidence of an unconformity between the Kaimur and Rohtas stages anywhere along the main boundary; but though there may be no unconformity here there must have been one not far off. Along the whole of the scarp from Gurdah to the eastern limit of the map there are found, in the lower Kaimur sandstone, fragments of chert which appear to have been derived from the Rohtas limestones. In places, as, for instance, north of Susnai (Susuneyee) these are abundant enough to form a breccia; the fragments are always angular or only slightly rounded on the corners and are not found in the bottommost beds of the Kaimur, but some way, even to a couple of hundred feet, above it.

If derived from lower Vindhyan rocks, and there is no other known source, these chert fragments indicate a considerable lapse of time, disturbance, and denudation. They must have been indurated into chert, the beds they were contained in elevated and the overlying beds removed by denudation before the deposition of the beds in which they are now found.

Relation of lower and upper Vindhyans.

The relation of the upper to the lower Vindhyans is consequently as follows. Along the boundary of the main area of the upper Vindhyans there is either direct evidence of conformity between the Kaimur and Rohtas stages or an absence of evidence of unconformity. Where the upper Vindhyan boundary turns southwards in the Mirzapur district there is evidence that the lower Vindhyans had been elevated and exposed to denudation at the time the lower Kaimur sandstones were being

deposited ; but the place where these conditions prevailed was away from, and probably to the south of, the present Kaimur-Rohtas boundary. Lastly, we find that, in the outliers south of the Son, beds of upper Vindhyan, though not necessarily of Kaimur age, are in absolute unconformity to the lower Vindhyans, which had undergone almost the whole of their present disturbance and been exposed to great denudation before the deposition of the sandstones of the outliers.

An old mountain range.

The explanation of these anomalies is to be looked for in the conditions of deposition of the Vindhyan system. In the second edition of the Manual of the Geology of India[1] I showed how the boundary of the Vindhyans towards the Aravalli mountains was precisely analogous to that of the Siwalik series and Gangetic alluvium towards the Himalayas, and suggested that just as the Siwaliks and Gangetic alluvium were formed during the elevation of the Himalayas, and of the *débris* washed down from those mountains, so the great Vindhyan system is contemporaneous with the original elevation of the Aravalli mountains and formed of the *débris* washed down from them while they were still growing and a far more important mountain range than the relics which remain at the present day.

The Aravallis were probably not the only mountain range of that period, and it is not too much to suppose that another range ran along the southern edge of the Vindhyan area, along and south of the present valleys of the Narbada and Son. In this case the peculiar relation of the upper to the lower Vindhyans would find an easy explanation ; they would naturally be conformable in the area of deposition beyond the limits of the zone of folding and mountain-formation, while within that zone the lower Vindhyans might easily be compressed, elevated, denuded and then covered up by later deposits of the same system ; just as we find the tertiary deposits of the extra peninsular hills showing great unconformable breaks on one section and on another a perfectly conformable sequence.

[1] Page 103.

In the Son valley the analogy with the Himalayas is, however, imperfect. There are no great faults with a downthrow to the north to represent the great boundary fault of the Himalayas and the minor boundary faults which divide the tertiary zone along their southern foot. On the contrary the principal faults of the Son area, though none are comparable in size to the boundary fault of the Vindhyans with the rocks of the Aravalli mountains, have their upthrow to the north, and the dips of the lower Vindhyans in their outliers is also northwards against these faults. The conditions are therefore at first sight the reverse of what prevails along the southern margin of the Himalayas, and in a previous paper I pointed[1] this out as a possible difficulty in the way of the explanation of the relation of the upper and lower Vindhyans in the outliers south of the Son adopted in the preceding paragraph.

Absence of great boundary faults.

A fuller examination of the Son valley area and a wider consideration of the general conditions of the problem have convinced me that there is no weight in this objection. On the one hand, just such a boundary fault as is required by the analogy is found just west of the area included in the map, whence it can be traced for some distance into the Narbada valley. To the eastwards, in the area covered by the map attached to this memoir, the run of this fault would carry it into the area covered by the rocks of the Gondwana system. In this case we might suppose that the main boundary fault exists, but is hidden to view, and that the area of transition and lower Vindhyan rocks exposed between the Kaimur scarp and the Gondwana boundary is part of the upraised floor of the old area of deposition north, *i.e.*, outside, of the main boundary fault.

A boundary fault to the west.

Against this supposition there might be put the degree of disturbance of the lower Vindhyans, which is greater than we have any reason to suppose has taken place among the deposits of tertiary or later age south of the outermost boundary fault of the Himalayas. Besides this the occurrence

Dying out of the boundary fault.

[1] Rec., Geol. Surv. Ind., Vol. XXVIII., p. 144.

of transition rocks north of the presumed run of this boundary fault, which further west brings them into contact with upper Vindhyans of the Rewah series, shows that the throw must have been largely reduced either by a subsequent movement of elevation of the northern side, or more probably by an original dying out of the fault.

In the latter case, we must look for the existing analogy to the conditions of this area during the Vindhyan period not in the Himalayas, but in the hills of Baluchistan and Sind, where the mountain-forming forces have acted with much less intensity, and where we may be regarded as having to deal with the limit of an area of principal mountain formation. In these hills there is no main boundary fault separating the disturbed rocks of the hills from the undisturbed deposits of the plains, and the beds which are confined to the marginal portion of the Himalayas rise up into, and are involved in the disturbance of the rocks composing, the mountains. Here we have the rocks of the tertiary system thrown into folds, and in places denuded before the deposition of nearly horizontal beds of the newer series on the eroded edges of the upturned beds of the older series. The conditions are, in fact, similar to those exhibited by the Vindhyans of the Son valley, and we may conclude that the mountain range which rose south of the present valley of the Son during the Vindhyan period bore much the same relation to the Aravalli range of that period which the existing hill ranges of the Western frontier do to the Himalayas.

Gondwana system.

The rocks of the Gondwana system exposed along the southern margin of the area under description present no noteworthy peculiarities. All the principal stages are represented, the Talchirs only by two small outliers, and are of the normal types described in the Manual of the Geology of India. The boundary to the older rocks, however, presents peculiarities which deserve special notice.

Boundary with older rocks.

From the Son to the Banas the boundary runs in a nearly straight line and is what would be called a faulted boundary by most observers. East of the Banas

the boundary takes a southward turn and, for a while, is irregular in form, ceases to show any sign of faulting, and becomes a natural boundary along which the sandstones of the upper Gondwanas rest in unconformable contact on the crystalline rocks. After the southern trend the boundary once more becomes a faulted one, continuing so to near the Gopat, where for a short distance it seems to become normal once more, but shortly after crossing the Gopat resumes its faulted condition, which it maintains to near the limit of the map. Near and beyond this the boundary once more becomes one of unconformable superposition.

The detailed examination of the Gondwana boundary has been of interest, as it was in this area, though further to the west, that Mr. Medlicott arrived at the conclusion that the apparently faulted boundaries were in reality due to the accumulation of the Gondwanas against inland cliffs. This opinion led to two very divergent views of the original extent of the Gondwana deposits: one school regarding the present limits as due to the removal by denudation of the upheaved portion of the beds, the other regarding the original extent of the formation as very much the same as its present distribution, and considering that the supposed faulted boundaries were an error of interpretation.[1]

The differences have been completely reconciled during the recent survey and the true nature of the boundary been elucidated; this finds its most complete and explicit expression in the section east of the Gopat, carefully examined by Mr. Vredenburg, whose description will be found in Chapter VIII.

Contemporaneous faults.

Put briefly, it may be stated that the Gondwana beds were deposited against inland cliffs, but these cliffs were fault cliffs, that is to say, they were the result of an immediately preceding movement along fault planes, which movement resulted in a decided inequality of the surface. The faults to which these cliffs owed their origin were not, however, wholly antecedent to the formation of the Gondwanas. Movement took place along them during the Gondwana period, and so it results

[1] Manual, 1st Ed., Vol. I., p. 103; 2nd Ed., p. 154.

that the deposits of this age are not in their original relation to the older rocks they were deposited upon, but have been subjected to a certain amount of displacement.

The boundaries are consequently faulted in a sense, but not in the ordinary sense of being determined by faults altogether posterior in date to the accumulation of the beds they cut; they are rather of the nature of boundaries of original deposition; that is to say, their gradual development led to the formation of the hollow in which the Gondwana beds were deposited. At times deposition more than kept pace with the formation of the fault and the deposits spread over it into the upthrow side to the north, as is shown by the few small outliers still found close to, but north of, the main boundary. For the most part, however, the deposits can never have spread beyond the fault scarps which bounded the area of deposition, and the present limit of distribution of the Gondwanas must be very much the same as their original limit of formation.

A fresh period of disturbance.

It will be seen from this that there have been two great periods of tectonic disturbance in this region. The first was the Vindhyan period of mountain formation by compression, the second is the Gondwana period of surface faulting, unaccompanied by compression. These two systems of disturbance appear to have been completely independent of each other. The faulting of the Gondwana period, even within the area of the map attached to this memoir, can be seen to obliquely truncate the broad area of the transitions, and further west the upper Gondwana boundary crosses the whole width of the lower Vindhyan outcrop and rocks of that age are found in close proximity to, though not in actual contact with, the upper Vindhyan sandstones.

Not of compression.

This means that the system of disturbance by compression of the Vindhyan epoch had completely come to an end and the mountains of the Vindhyan epoch had been lowered by denudation and perhaps by actual subsidence, when the new system of disturbance set in. This, so far from being one of compression, must have been accompanied by an actual

extension of the surface. The crust of the earth was divided into plaxes,[1] separated from each other by fractures reaching deep into the earth and along which differential movements of elevation take place. Not only was the nature of disturbance which took place utterly distinct from that of the Vindhyan epoch, but the direction of the main line of disturbance is different and cuts obliquely right across the area of the mountain range of Vindhyan age.

Age of the Vindhyan system.

From this it is evident that there must be a considerable difference in time between the two different systems of disturbance, and in this manner we may get a hint of the age of the Vindhyan system. The Gondwana system of disturbance had commenced in Talchir times, that is, in the permian epoch. The lapse of time from the cessation of the Vindhyan compression must have been considerable, and we can, consequently, hardly regard the age of the newest beds of the Vindhyan system as of later age than devonian. How much older they may or may not be there is no means of deciding.

Recent deposits.

Recent or surface deposits are largely developed in the area under consideration ; in fact, they are ordinary stream deposits of sand and gravel, which in places have been compacted by a calcareous cement into sandstones and conglomerates. The actual area occupied by these recent deposits at the surface is very small, even in the Son valley, where they are most largely developed. Enormous areas are, however, covered by a form of recent deposit which, so far as it has been noticed by previous observers at all, has been described as alluvium, but to which this term seems inapplicable in its proper sense.

Fine-grained loam.

The deposits referred to are fine-grained and unstratified. When wet they pass into a slimy and impalpable mud, when dry they indurate to the consistency of rock. As seen in the sides of drainage channels they show no trace

[1] The word *plax* was suggested by me (Mem., Geol. Surv. Ind., Vol. XXIX., p. 167) as a more satisfactory equivalent of the " scholle " of German geologists than the word " block," whose use is liable to ambiguity.

of lamination, break off with a vertical face, and sometimes are penetrated by numerous small, sinuous, and branching tubelets. When this structure is present they resemble the typical loess of the Rhine, but more often they form an amorphous loam.

Mechanical composition.

The laboratory of the Geological Survey is not equipped with apparatus for the physical analysis of soils, but an approximate determination of the nature of this deposit was made by subjecting some samples to sieving and passage through an elutriata, which was found by experiment to remove sand grains of less than ·01 mm. ($\frac{1}{2500}$ inch) in diameter. On passing the samples through this it was found that from 70 to 90 per cent. was washed away and that the greater part consisted of ferruginous and calcareous concretions, and only about ·5 to 2 per cent. of mineral grains. Of the 70 to 90 per cent. which was removed by the elutriata a large proportion settled in still water if left standing for a couple of minutes, but a marked turbidity of the water remained and a notable proportion was fine-grained mud which settled, in water, at a rate of not more than an inch in a minute.

It is remarkable that even this fine-grained mud consisted in part of grains of carbonate of lime, and effervesced on treatment with mineral acid.

Not of aqueous origin.

It is impossible to account satisfactorily for the formation of these deposits by water. The material of which they are composed would only settle in water that was absolutely still, but they present none of the characteristics of a fine-grained sub-aqueous deposit. Into a lake or pool mud is washed down at intervals by floods, the coarser grains settle first, followed by the finer grains which subside more slowly, thus producing a laminated structure which is conspicuously absent in the recent deposits under consideration. In a river valley and as the result of alluvial deposition such fine-grained, unlaminated deposits are impossible, except as very local accumulations.

Surface forms.

The surface contour is equally inconsistent with their aqueous origin. Instead of forming a level plain, sloping down the valley, but extending horizontally on

either side to the foot of the bounding hills, or with a slight slope downwards from the centre, they form a shallow concave trough-shaped surface, rising on either side towards the hills; or in the larger plains, such as those of the main valley of the Son, they have a gently undulating surface, in whose hollows rainwater accumulates.

Dust deposits.

The difficulties in the way of an aqueous, or alluvial, origin of the deposits disappear if we regard them as dust deposits formed from the air. The composition is that of the fine particles into which the surrounding rocks disintegrate, the fine grains which would only settle with extreme slowness in water would settle rapidly in air, and the absence of lamination would be accounted for by the action of vegetation, which would also serve to catch and retain the dust settling on the ground, and protect it from being removed by subsequent gusts of wind. The absence of lamination may also be partly due to the gusty nature of the winds and especially to the numerous small whirlwinds which traverse the country in every direction during the hot weather. These pick up the loose soil and dust on the surface of the ground, and after whirling it high into the air, allow it to settle tumultuously and without any sorting into widespread layers. They are also doubtless the means by which the occasional coarser grains are carried out from the hills into the plains, and these deposited among the vastly preponderating bulk of fine-grained dust.

Distribution.

The deposit is, besides, by no means confined to the valleys, but is found on the sides and tops of the hills, wherever a sheltered hollow exists, in which dust and sand, swept from the surrounding hills, can settle. The strong winds of the hot weather, sweeping over a parched and friable soil, strip the rocky elevations bare of soil, or of all but a thin layer of soil retained by a scanty growth of grass, and the roots of trees speading over the surface of the rock. But where there is a sheltered nook, or on the broad and open plains where there is no prominence to oppose and so increase the force of the wind, the dust blown from the surrounding hills settles and accumulates.

In accordance with this mode of origin is the variation in the

character of the deposit. In the lower Vindyhan area, where limestones are abundant, the calcareous concretions are especially abundant. In the transition area such are rarer and ferruginous concretions are as common, and in places more abundant than, calcareous, while in the Gondwana area, where limestone is wanting and iron oxide common, the concretions are principally ferruginous. So also it was noticed that in and near the outcrops of the red shale series the fine-grained surface deposits had usually a distinctly reddish tinge, while away from them the colour was usually a pale grey, sometimes ranging to dark grey or nearly black.

CHAPTER III.—PHYSICAL GEOGRAPHY AND ITS EVOLUTION. (R. D. OLDHAM.)

Kaimur scarp.

The most striking physical feature of the area under report is undoubtedly the great Vindhyan scarp, which also forms its northern boundary. This great scarp, known further west as the Kaimur range, extends from Sasseram in the east to the Narbada valley in the west, and throughout its length rises abruptly to heights which range from 500 to over 1,000 feet above the low ground to the south. Throughout this length too it forms the waterparting, except for a few small streams that break through to the south and will be referred to further on, between the drainage which finds its way northwards to the Ganges, and that of the great strike valley of the Son and its westerly continuations on the south.

Son valley and hills to the south.

South of the Vindhyan scarp comes the low ground of the Son valley occupied by rocks of lower Vindhyan age and deeply covered by extensive dust deposits, from which rise a number of prominent ridges, formed by the harder beds of that series. South of this again comes a mass of low hills, forming more or less parallel discontinuous ridges and traversed by a series of rivers running northwards across the strike of the rocks of the transition systems which occupy this area. To the south of this mass of hills comes the more open ground of the Gondwana area, at first distinctly lower than that occupied by the transition rocks, but further south rising into high, flat-topped plateaux with irregular scarped faces, similar in general character to those of the upper Vindhyan area.

The surface features are directly dependent on the structure of the different areas and on the differential action of denudation on the hard and soft beds of which they are composed. When the stratification is horizontal or nearly so, we get flat-topped plateaux surrounded by steep scarps; where the beds are tilted at high angles we get more or less continuous straight, and sharp-crested ridges.

It is, however, noteworthy that these ridges are most continuous and even-topped in the lower Vindhyan area when the beds are comparatively less disturbed and dips seldom rise above 60° than in the more highly disturbed transitions where dips of over 45° are the rule and vertical dips are by no means uncommon.

Connection between dip and form of scarp: Theoretical consideration.

In part this is due to the greater disturbance of the transitions and to the fact that the termination of the ridges is frequently due to a cutting off of the hard bed by a fault, but to a large extent it is the direct result of denudation. To understand this let the case of a hard bed among softer strata be taken and let it be assumed that the hard bed is traversed by joints running at right angles to the bedding planes, along which it breaks off; the hard bed may be assumed to stand at all angles up to vertical, while the softer beds stand at an angle of only 30°; further, we may assume that equal amounts of the hard bed are removed in equal times and that the surface contours of the soft beds protected by the hard one adjust themselves to the altered conditions *pari passu* with the removal of the hard bed. The conditions postulated are not very different to those met with in nature, and the results obtained may be applied with but little modification.

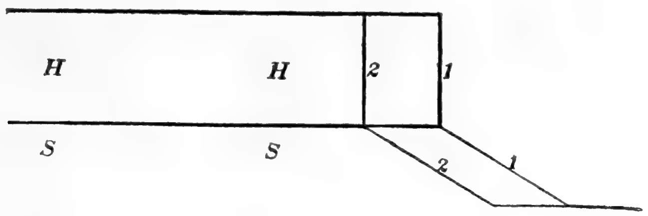


Fig. 1.

To commence with a condition of horizontality of dip, as represented in Fig. 1, it will be seen that the removal of a portion of the hard bed, H H, which will cause the surface contour to recede from 1 to 2, makes no change in the height of the

plateau, but causes its scarp to recede by the breadth of the slice of the hard bed removed.

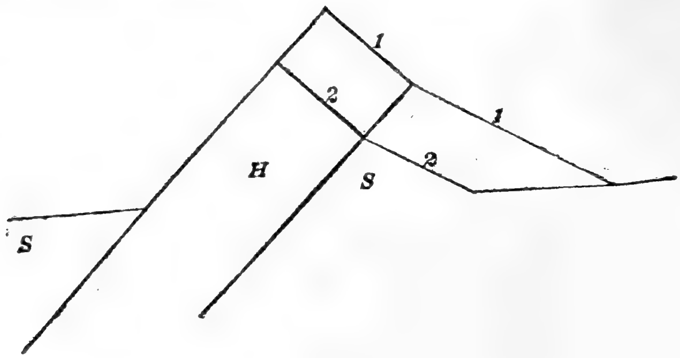


Fig. 2.

Taking now the case of a dip of 45° as represented in Fig. 2, it will be seen that the removal of an equal amount of the hard bed causes the crest of the ridge to recede, but not to the same extent as in the case of a horizontal dip, while the crest is at the same time lowered. For a dip of 45° the change of height and the horizontal shift are equal, for other angles they will be to each other in the ratio of the sine to the cosine of the angle of dip. For angles less than 45° the horizontal shift exceeds the vertical lowering, and for angles above 45° the reverse is the case, the amount of lowering becoming greater and the horizontal shift becoming less till we reach the condition of vertical dip represented in Fig. 3. Here the removal of the hard bed has no effect whatever on the position of the ridge, but its height is lowered by the whole amount of the slice removed by denudation.

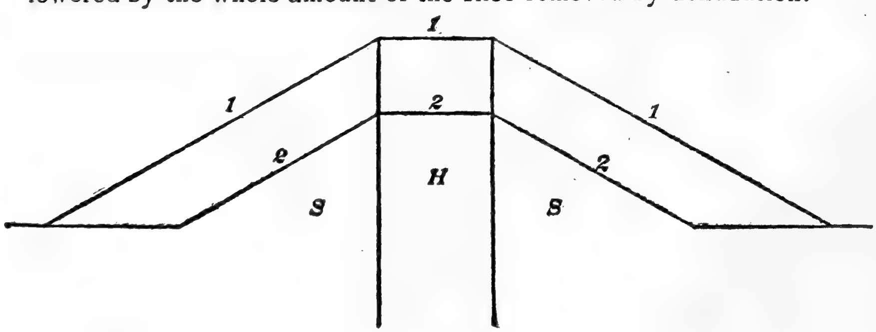


Fig. 3.

In this investigation we have considered merely the effect of denudation on a single section. In nature this is not uniformly distributed, but has greater effect at certain places than at others, owing to variations in the vigour of the attack, caused by the concentration of drainage in greater or smaller stream channels, and to variations in the power of resistance of the rocks, caused by variations in the degree of induration, and more especially of the number of joints by which it is cut. As a result of this the amount of the hard bed removed in a given time will vary at different points, and the effect will be that where the dip is horizontal we will find great irregularity in the outline of the edge of the plateau, but none in its height; where the dip is vertical we will find no deviations from a straight line but great variations in the vertical profile of the ridge, while at intermediate angles the variations of either kind will be less, one or the other preponderating according to whether the dip is under or over 45°. From this it will be seen that the best marked ridges, that is to say, those which vary comparatively least from a straight line, and an even crest are formed not by vertical beds but by those inclined at an angle of about 45° or more, and the effect is emphasized in nature by the fact that in these circumstances the whole of the denudation would not be from the end of the hard bed, but in part from its upper surface too, as indicated in Fig. 4. Here the removal of material from the dip surface throws the crest towards its original position and, if the total amount removed is the same, lessens the diminution of height.

Unequal amount of denudation.

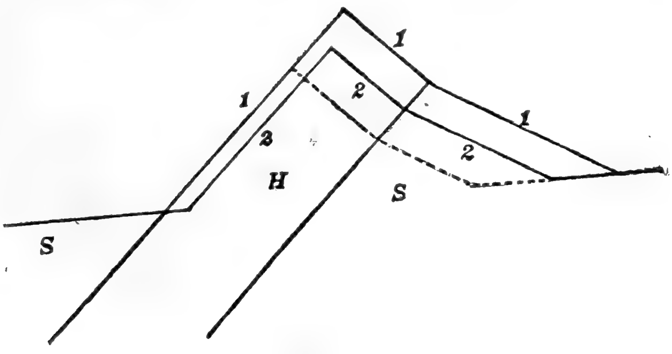


Fig. 4.

From these considerations it is seen that the most continuous ridges should be formed by beds dipping at about 45°; where the dip is low there will be flat-topped scarps, showing much irregularity of outline in detail ; where the dip is high there will be a straight ridge, rising into peaks and crags, but interrupted by low gaps.

Agreement with observed facts.

This is exactly what is found to be the case, the scarps of low dipping Vindhyan and Gondwana rocks show great irregularity of outline in detail, even where they exhibit a marked constancy of general course. In the lower Vindhyan area, where dips of from 40° to 60° are found, the long, straight and continuous ridges are a marked feature, and in the transition area, where higher dips are the rule, we find the ridges very uneven in height, rising into peaks separated by deep saddles, which often descend nearly or quite to the level of the low ground between the ridges.

Diversion of drainage.

As in all areas which have been exposed to subaerial denudation for any length of time, there are numerous indications of changes in the course of the drainage, and the ridges are pierced by "wind-gaps," marking places where they had once been traversed by streams which have now been directed to other courses. One such is represented on Plate 1, and another case may be noticed where the diversion of the drainage is not quite complete.

Kushmahar gap.

About fifteen miles east of the junction of the Banas and Son rivers, and of the point where their combined waters pass through the ridge of the bottom quartzites of the lower Vindhyan series, the map shows a small stream flowing through the continuation of this ridge and draining a small area near the village of Kushmahar. The gap through the high ridge is, however, not in keeping with the size of the stream which now flows through it ; instead of being a narrow gorge it is an open valley through which one of the principal tracks of the neighbourhood runs and at whose bottom flows a small streamlet quite incapable of forming so large a valley, or even of keeping open a valley through this ridge of hard quartzites.

If the map is examined it will be seen that on either side of the head waters of this stream is an expanse of crystalline gneiss. On the one side is a tributary of the Banas, on the other of the same stream which the Kushmahar drainage ultimately joins, to flow into the Son near Bhelki. Formerly the stream which flowed through, and carved out, the gap north of Kushmahar must have been larger than it now is. It had, however, not the same power as the combined waters of the Banas and the Son and the gap through which they flow was cut down faster than that at Kushmahar. As a result the tributary of the Banas which flowed from the east, had a steeper fall than that of the Kushmahar stream, which flowed from the west, the valley of the former was gradually lengthened by a cutting back of the watershed and the drainage area of the head waters of the Kushmahar stream reduced.

Encroachment on drainage area

due to greater power on the west,

Meanwhile this drainage area was being attacked on the other side, but for a different reason. On the east there is no large and powerful stream like the Banas, but it will be seen that the eastern branch of the combined waters, that called Eonar N. on the map, flows over the easily decomposed crystalline gneiss and crosses the boundary of the lower Vindhyans in a region where the basal conglomerates, as mentioned in Chapter VII., are thin and incapable of forming a pronounced ridge. Here we have less power than in the Banas, but very much less resistance to be overcome than by it, or by the Kushmahar stream. As a consequence this eastern branch has been able to lower its bed faster than the Kushmahar stream, and by cutting back its watershed to reduce the area of its drainage basin. The volume of the Kushmahar stream, and consequently its power, has thus been reduced by encroachment on its drainage; it will no longer be able to lower the gap through the quartzite ridge at a rate that will enable it to preserve its individuality in opposition to the opponents which are attacking it on either side and the

and to less resistance on the east.

ultimate consequence will be that the whole of this drainage area will be captured by one or other of the two streams on either side, and the gap through the ridge will remain as a dry valley or "wind-gap."

Resulting direction of drainage channels.

These are by no means the only instances of changes in the course and distribution of the drainage which are to be met with; throughout the area surveyed there are numerous instances of such changes either completed or in progress and one of the consequences is that the stream-valleys almost without exception run about east by north and west by south along the strike of the softer beds, or north by west across the strike of the harder beds. This distribution of the drainage is most noticeable in the field and fairly well shown on the map, in spite of a somewhat inadequate delineation of the hills.

Concentration of drainage.

Another result has been a concentration of drainage in certain channels. Nothing is more certain than that a stream, having once been established in a given channel, cannot leave it to find another channel if this involves its flowing uphill even a short distance. Hence we find that rivers sometimes traverse a narrow gorge through a hill when there may be low ground on either side along which the more obvious course of the valley runs. But if a tributary of the same or a different stream cuts its valley back along this low ground till it intercepts the main stream, this will desert its former channel and take the easier course. So too if we have a series of streams crossing the strike of a hard bed and if, for any reason, one of them is able to deepen its channel faster than the others, then the tributary valleys of this stream, cutting back along the strike of the soft beds, will intercept more and more of the other streams and cause more and more of the drainage on the up stream side of the hard bed to be concentrated in one channel.

Samdin valley.

An instance of this concentration of drainage is to be seen in the Samdin. Below Sejari this traverses a gap between a ridge of hard Bijawar quartzites on

the east, which had been cut off by pre-Vindhyan denudation and do not extend to the west of the river, and the termination of the Kharara plateau on the west. There is here a small gap of comparatively soft rocks between two ridges of hard rocks, and through this the Samdin flows.

If the course of the Samdin had been determined when the surface of the land stood at a higher level than now, there would be no reason why just this particular place should have been selected; but if we suppose that there were formerly several small streams flowing northwards instead of one large one, and that one of these flowed somewhere near the soft gap, it would cut its bed down more quickly than the others, and at the same time its tributaries would break into the drainage of the other streams which had not been able to lower their channels so rapidly. The increase of volume consequent on this would enable it to lower its valley still faster and, extending back into the soft and easily eroded sandstones of the Gondwanas, to rapidly extend its drainage area and power.

The Banas valley.

The Banas is a similar instance. Its passage through the main range of the lower Vindhyan basal conglomerate was doubtless determined by the gorge of the Son, but the passage through the conglomerates of the red shale series and lower Vindhyans near Naoria has been determined by a very marked flexure in the rocks, accompanied by shearing in a horizontal direction, which has lessened the power of resistance of the rocks at this point. Like the Samdin we have probably a case of concentration of drainage at this point, and similarly most of the chief streams draining to the Son are found to have their courses across the hard beds coincident with a reduction in their thickness or with some structural peculiarity which locally lessens their power of resistance.

A coincidence of this kind is not conceivable if the courses of the principal drainage channels had been determined when the surface of the land formed a plain at a higher level than the tops of the present hills and had then cut down along their courses to the present level. It proves that the land has been for a long period

exposed to subærial denudation during which there have been extensive changes of the drainage system; and shows that the present river channels may be very different from those of the drainage system previous to the last considerable change in the levels of the district.

Gopat valley.

A possible exception may be found in the Gopat, which, flowing obliquely across the strike of the rocks and nowhere showing any special reason for following its present course, except in detail, may be an ancient river which has had power enough to preserve its original course and resist diversion by other streams. The Son above its junction with the Mahanadi crosses the lower Vindhyan area without any reference to the lines of least resistance, and being a large river with a very extensive drainage area to the south, may be an ancient river which has not suffered diversion during the gradual lowering of the general surface of the country.

Valley of the Son.

At present the determining factor in all erosion which is going on is the great strike valley of the Son, which defines the base level of the tributaries flowing from the south; but this itself seems to be the greatest and most remarkable instance of diversion and concentration of drainage in the district. The hydrography of the Son valley, as may be seen from any good map of India, is peculiar. Throughout its length it receives no tributary of any importance from the north, but on the south it receives a number whose sources reach a distance, measured in a straight line, of a hundred miles from the main stream. On the north the watershed is parallel with and close to the river, and from the crest of this watershed another series of rivers flow more or less northward to the Ganges. The Son drainage system is consequently a one-sided one and in this is exceptional among river valleys of so large a size.

The Kaimur scarp.

Not less remarkable than the Son valley, which intercepts and carries off the drainage of so many tributaries from the south, is the great Kaimur scarp,

which bounds it in the north, running close to and parallel with the river from Sasseram on the east to the sources of the Mahanadi. Throughout this length of nearly 300 miles as also throughout its continuation in the Narbada valley, it is not breached at a single point by any stream flowing northwards, nor, with a few trivial exceptions, by any stream flowing from the north to join the Son. Everywhere it rises abruptly to a height of from 500 to over 1,000 feet above the low ground at its foot, and though the height of the crest varies from place to place, through undulations of the strata or the varying amount removed by denudation, there is nowhere any deep-cut gap or easy pass from the north to the south of this range.

Such a feature is, so far as I know, unique in physical geography. Escarpments of great length are known, but they are all breached at intervals by streams which flow through them, usually, as in the classic case of the chalk escarpments of the Weald, from the scarp side towards the dip. These cross-valleys are almost a necessary consequence of the current theories of the formation of escarpments, which presuppose a plain or peneplain at a general elevation, greater than the crest of the present scarp. Across this plain rivers were initiated whose general course would be down the slope, that is to say, usually in the direction of the dip, and as they gradually cut their channels down their side streams would more rapidly attack the soft beds, wearing them away and leaving the harder beds standing out as scarps.

Northward trend of drainage interrupted by the Kaimur scarp.

In the Son valley and the Vindhyan plateau to the north we have a generally north, that is, dip-wards course of the drainage ; we have also the Kaimur scarp due to the removal of the softer beds of the lower Vindhyans and the standing out of the harder upper Vindhyan sandstones ; but instead of any of the northward flowing streams continuing their course through gaps in this scarp they are one and all intercepted by the principal river of the district, which flows along the foot of the scarp. Not only is this the case as regards the actual course of the drainage, but there is no

unmistakable indication of any considerable stream having flowed in this direction; there is no deeply-cut wind-gap to show where a river once flowed, before it had been intercepted by the growth of a valley cutting backwards along the strike.

This peculiar orography and hydrography can only be explained by a consideration of the geological history of this region and itself seems to throw light on the vicissitudes it has undergone during the long period it has been exposed to subaerial denudation.

Original course of drainage.

In the Vindhyan period, and at the time when the mountain chain still existed, the course of the drainage must have been northwards from the mountains across the plain of deposition in which the Vindhyan system was being deposited. By the time the deposition of the Gondwanas commenced, this mountain range had subsided, and as the low ground and the area of deposition lay to the south, we may conclude that the drainage was in that direction; we cannot, consequently, look for any trace of the original Vindhyan drainage in that of the present day as it had been obliterated and replaced by a different system even in Gondwana times.

Long period of subærial drainage.

After the close of the Gondwana epoch, a time corresponding to the close of the jurassic period, we have no direct geological evidence of what occurred. We know that neither this nor any other part of the peninsula has been under the sea since a much earlier period of geological history, but after the close of the upper Gondwana period no great changes seem to have taken place till the great outburst of the Deccan trap. It seems certain at any rate that any changes which may have taken place did not lead to the accumulation of deposits sufficiently extensive for them to have been preserved till the present day.

Reduction of surface relief.

What happened during this long lapse of time there is no direct means of knowing, but there are not wanting indications that the country was reduced to the condition of low relief, which has come to be known as a peneplain. If the trigonometrically determined heights of the

principal peaks, as entered on the map, are examined, it will be seen that they all rise to about the same level. There is a gradual drop from west to east and the heights in the transition area are somewhat greater than those of the Vindhyan scarp opposite to them. In other words, they might well be the remnants of a gently undulating peneplain which has since been carved out by rivers to a generally lower level. Seen from one of the higher peaks of the transition area this impression is more strongly felt ; all the higher peaks are seen to rise to about the same general skyline, about level with that from which the view is taken, as is well shown in the sketch on Plate III.

From this it seems probable that there was at one time a surface of low relief from which hills rose to heights of perhaps three or four hundred feet above the stream-beds, but by gentle slopes from broad open valleys. The general slope of this surface was about north-eastwards from the high Gondwana plateau to the south, and, as already suggested, the Gopat valley across the transition area may still mark the general course of one of the rivers of this time.

The great Kaimur scarp must have been marked out at this time and not far from its present position, but would have a much less elevation above the general surface than now. Whether any of the drainage from the south passed through it northwards, or whether there was, as now, a river flowing along the strike of the lower Vindhyans, cannot be directly decided. In the long course of time during which this area had been exposed to subærial denudation it is probable that the outcrop of the soft beds of the upper stages of the lower Vindhyans had already determined the position of one of the main drainage lines of the region ; but whether this was so or not the lower Vindhyan outcrop must have been marked by a tract of low ground lying between the higher ground formed by the harder rocks of the transitions to the south, and the Vindhyans to the north.

Renewal of surface relief.

However this may be, the last great change, which led to the elaboration of the present surface features was one of elevation, which enabled the rivers to

cut down, and if the Son had not previously been evolved as a river carrying off the drainage of the country south of the main area of the upper Vindhyans, it then cut its way back along the outcrop of the soft beds of the lower Vindhyan series and diverted the drainage to the eastwards.

Against the supposition that the present course of the Son is not of geologically recent origin, and due to diversion of drainage, must be placed the absence of any considerable tributary joining it from the north. Had the present valley of the Son been an ancient main drainage channel, antecedent to the last great uplift, it is difficult to understand how no valley had been formed on its north side; yet at the present day the tributaries from the north are few and inconsiderable.

Northern tributaries of the Son. The Ghagar.

The most important is probably the Ghagar, which joins the Son near Chopan, issuing from the upper Vindhyan area near Markundi, and this bears the impress of being a new stream which has cut its way back from the Son. At Markundi the Vindhyan scarp bends southwards and cuts across the axis of an anticlinial; the Kaimur sandstones, too, are here divided by a band of shales, the Bijaigarh shales, along whose outcrop the Ghagar flows for some distance in from the boundary of the upper Vindhyans, in a deep-cut steep-sided valley showing every sign of erosion being in active progress at the present time. The stream breaks through the scarp of the upper Kaimur sandstone in a narrow steep-sided gorge, and its upper waters drain a fairly large area on the plateau of the Kaimur sandstone.

The lower part of this valley presents none of the features of an old valley; it appears to have cut its way back along the outcrop of the Bijaigarh shales and then through the scarp into the plain, covered by recent deposits above it. The features would not be incompatible with the valley having been in existence prior to the last great uplift, the signs of erosion would then be due to this small stream not having cut its bed down at the same rate as the

more powerful Son, but the erosion is so far behind that of the main valley that this supposition is unlikely. If on the other hand the Ghagar valley is altogether newer than, and formed by cutting back from, the valley of the Son, the appearance of recent and active erosion which it presents would be in keeping with what should be expected.

The elucidation of the origin of the Ghagar valley is complicated by the fact that there is no present indication of a cutting back of its head waters on the plain above the Kaimur scarp. In the case of the Adh, the next largest and only slightly smaller tributary from the north, the evidence is complete.

The Adh valleys.

In Rewah territory it will be seen from the map that the Kaimur range is double, consisting of two scarps, of which the southern is formed by the Kaimur sandstone and the northern by the upper Rewah sandstone, the low ground between being occupied by the less resistant shales and sandstones of the lower part of the Rewah series. From about Long. 82° E. the depression is occupied by the strike valley of the Adh river draining eastwards and ultimately to the Ganges. From the watershed at the head of this valley another stream, also known as the Adh, flows westwards for about ten miles, when it is joined by a stream which has flowed eastwards for nearly the same distance through a similar valley, and the combined waters break southwards in a precipitous-sided gorge, through the Kaimur scarp and as the Narkuni (Narkooi) Nadi flows into the Son.

At the watershed between the eastern and western Adh, there is a broad open valley, filled with recent deposits, whose surface has been a good deal eroded and rendered irregular. To the north is a small valley draining from the Rewah scarp which appears to have formerly drained into the eastern Adh, but to have been diverted into the western. Leaving this open plain and descending the western Adh it is found that the valley bottom soon drops somewhat rapidly and the stream-bed takes on an aspect of active erosion. The side valleys too seem to have recently been deepened, for a

greater or less distance up from the main stream, and there is every indication that this valley is cutting backward and lengthening itself at the expense of the eastern Adh.

Gorge at Khamerji.

Before referring further to the Adh valley it will be well to consider a miniature model of it which may be noticed on the map just north of Khamerji. Here a deep gorge will be noticed penetrating about a mile into the scarp, when it divides into two branches which separate at right angles to the main gorge and penetrate in opposite directions for about two miles to the west and one to the east of the junction. On examining the ground above these gorges it is seen that they are cut out of two open valleys whose position was determined by an open synclinal fold in the Kaimur sandstones and whose bottoms formerly lay at some 200 to 300 feet above the bottom of the present gorge, and which after uniting drained northwards, through a valley which can still be traced, to the Adh valley.

This valley was evidently tapped by a gorge which cut back from the south, its position being determined by a number of joints and some small faults of a few inches throw, which traverse the Kaimur sandstone just at this place. Having once cut back to and tapped the drainage of the high level valley its volume and consequently power was greatly augmented, the bed of the main gorge was lowered and from its head branch gorges were cut back along the beds of the streams which had now become its tributaries. Once the drainage was diverted into the new course and the bed of this lowered in consequence of the power added to the stream flowing along it, any return to the old course became impossible.

Diversion of drainage.

At the present day there is a short gorge cut back along the old course of the main stream, and in a direct line with the gorge through the Kaimur scarp. Ascending from this by the steep slope at its head one enters a broad open valley along the bottom of which an old stream-bed can be traced, though now only occupied after rain by a much smaller stream than that which formed it. Descending this, it is found to flow

over a gentle slope and through an open valley, showing no signs of erosion, as the present stream is quite unable to move the boulders left by its predecessor. After passing for some distance along this, marked signs of erosion commence, the stream-bed is deeply cut, has a much steeper gradient, and is blocked by large angular blocks of stone; there are, in fact, all the signs of active erosion and of a recession of levels along the stream-bed. Further down the gradient decreases and a boulder-strewn stream-bed reaches down to the Adh. Here we have the stream cutting its bed backwards from the recently lowered bed of the Adh which it joins, the change of level at the junction having been too recent to allow of the recession of levels having reached the watershed and so established a uniform slope throughout the length of the stream-beds.

Origin of the Narkuni gorge.

Returning to the western Adh we may suppose that the eastern Adh was once a part of a valley and whose head waters lay twenty miles or more to the west. Then, near where the village of Tikat now stands, a ravine cut its way back through the Kaimur scarp and tapped the upper waters of this stream. As a consequence of the increased power so obtained it rapidly deepened its bed, and from the lower level so established a tributary ravine began to cut back eastwards till at the present day it has attained a length of twelve miles, and, as we have seen, seems still cutting its way backwards at the expense of the eastern Adh.

Other valleys due to cutting back.

The very few other tributaries of the Son which penetrate the Kaimur scarp are all quite insignificant in size, and all have been most unmistakably formed by cutting back from the low level of the Son valley. This being so, it is natural to suppose that the valley of the Ghagar, whose aspect is quite compatible with a similar origin, was also formed in this way.

Antiquity of the Son valley.

We now come to the consideration of the antiquity of the east-to-west portion of the Son valley, and of its continuation above the bend in the Mahanadi

valley, that is to say, to the determination of whether this course was determined prior to or consequent on the last great uplift. This resolves itself into the possibility of determining whether there is any trace of drainage channels having crossed the Kaimur range from south to north.

No gaps through the Kaimur scarp.

Of this there is certainly no satisfactory evidence. The height of the crest of the scarp varies greatly and there are comparatively low gaps which have been selected as passes across the range, but they are all broad and open where they cross the crest, and there is no narrow notch such as would be cut by a river during a period of erosion. It must be remembered that if the drainage had been mainly northwards previous to the last great upheaval, and the Son had gradually cut its valley backwards diverting more and more of the drainage from the south, the cross valleys to the east might have had very little time to lower their beds in the upper Vindhyan area before they were diverted. Those further west, however, would have had more time, and one would expect to find at least a somewhat deep-cut valley marking the point where what is now the upper Son—above its junction with the Mahanadi—crossed the Kaimur outcrop to the low ground further north. No such low gap can be found, and, though there has been a certain amount of concentration of drainage since the Son last began to lower its valley, and the streams of a former period may have been more numerous and smaller than at present, it is difficult to account for the absence of such gaps, if the Son valley is of recent origin.

It will be seen from the foregoing that we have on the one hand the absence of tributaries from the north pointing to a recent origin of the present valley of the Son, and on the other the absence of wind-gaps in the Kaimur scarp pointing to its antiquity. Had we nothing else to depend on it would be difficult to choose between the two, but there is fortunately one peculiar feature in the course of the Son which affords what appears to be decisive evidence.

Southward bend of the Son.

For the most part the course of the Son lies in the comparatively unresisting rocks of the Kheinjua stage, occasionally wandering into the Rohtas area. Near Marai, however, it passes south of the termination of a scarp of Kheinjua sandstone and of an exposure of the porcellanites to flow for awhile in the soft shales of the basal stage, then turns abruptly through a narrow gap in the high ridge formed by the basal quartzites of the lower Vindhyans at a spot called Devalond, and after a course of about 25 miles over the crystalline gneiss once more breaks back through the continuation of the ridge of basal quartzites just below its junction with the Banas.

Gaps in the basal quartzite ridge.

At the lower gap there is a certain amount of disturbance of the quartzites which might account for the selection of this position for the gap, but at Devalond nothing of the sort can be seen. The quartzite ridge on one side is a continuation of that on the other and between them the Son flows in a deep and narrow gap. This is not to be explained by any diversion of drainage, and the only possible explanation of the bend of the Son to the south and its double passage through one of the most prominent ridges of the district, is that this course was determined at a time when the ridge did not exist, and that having once been determined, the Son was constrained to cut its way down and form the two gaps in the ridge, which itself grew in height by the more rapid removal of the rock on either side. In other words, the course of the Son was fixed at a time when the form of the surface was determined by different conditions to those it is now dependent on, and has been superimposed on the present surface features.

Son valley marked out previous to last great uplift.

The only period to which we can refer this original determination of the present course of the Son in this southern bend, is that period of reduction of the surface to a peneplain which has been referred to. At that time the relief of the land must have been much less than at present and the Son must have flowed in a shallow open valley, probably largely covered by alluvial deposits, and the

present ridge of the basal quartzites was either completely covered or only represented by a few knolls of rock. In this valley the river would be at liberty to wander from side to side, and at the period of the last great movement of elevation it flowed in a bend which crossed the outcrop of the basal quartzites in a loop not unlike its present course.

Once the movement of elevation commenced and the rivers began to cut down their channels, the course of the Son was fixed, and it was, where it crossed the harder rock, constrained to preserve its position and form two gorges through the range of basal quartzites which gradually grew in height as the ground on either side was lowered at a greater rate than the crest of the ridge. In this course the Son must remain till one of its tributaries, the Sohera for instance, cutting back along the softer rocks of the Kheinjua stage, intercepts the Son above Ghusa and diverts it from its present course.

Possibility of diversion of the Son from its southward bend.

Under existing conditions there seems no prospect of this, but if there were a fresh period of elevations which would set the streams at work on active erosion of their beds, there can be no doubt that the two barriers of hard quartzites would oppose a resistance to the erosive action of the Son which would prevent its lowering its channel in the Kheinjua beds above Marai at the same rate as it would be lowered below the junction of the Banas. This difference of level would affect all the tributaries and those which joined the Son below would have their gradients, and consequent power of erosion increased. The Sohera would cut back its watershed and divert the waters of the Nagour above Deora into its channel, after which a tributary of this river would cut back along the strike of the shales south-westwards of Deora till the watershed was cut back to the Son, and the waters of that river diverted into a new and easier course.

Present a period of comparative repose.

As already indicated there are no signs of the probability of such diversion taking place under present conditions. The present appears to be a period of comparative repose, the streams have nearly attained a condition

of equilibrium, and the only change which seems to be taking place is a slow degradation of the hills; changes of the drainage system, by encroachment of one drainage area on another, are local and not likely to affect the general course. In the immediate past, however, there seems to have been a period when all the streams were engaged in active erosion of their beds and in consequence shifting of the watersheds and diversions of drainage common. To the repetition of processes similar to that which has been prophesied above, in the event of a period of rapid erosion setting in once more, we must probably ascribe the manner in which the Son now flows along the soft rocks of the Kheinjua stage. It is improbable that there was only one place where the Son bent southwards from the outcrop of these beds, and it is more probable that lower down its course these bends have been cut off by the more rapid lowering of the soft ground and diversion of drainage. By the time the re-adjustment of levels had extended as far up stream as the head of the east-and-west Son, the difference of level between the bed above and below its southern bend had become too small to allow of the diversion of this bend to be completed, and it will remain till a fresh period of elevation and erosion sets in.

Son valley determined by adjustment previous to last great uplift.

From the foregoing we see that the general east-to-west course of the Son must have been determined at the time when the general surface of the ground was reduced to a condition of low relief, and before the last great movement of elevation. It cannot, consequently, be ascribed to diversion of drainage during this period, and we see that the general course of the main stream of the Son, though it must be due to the greater softness of the lower Vindhyan shales, and to diversion and concentration of drainage by cutting back of the watersheds along this soft band, was determined some time in the long ages during which this region has been exposed to subærial denudation prior to the last period of upheaval and active erosion.

Amount of last great uplift.

We are also able to form some estimate of the amount of the elevation which has taken place during this last period, and of the height of the Kaimur scarp

at its commencement. The general level of the bottom of the Son valley must have been at least as high as the present crest of the basal quartzite ridge, which could not have existed as such when the present course of the Son was determined. The highest crest of this ridge now stands at 1,615 feet above the sea, or rather over 600 feet above the bed of the Son; as this peak itself must have been lowered by denudation from the height due to it from the elevation alone, we may take it that the general lowering of the Son valley, which cannot be widely different from the amount of elevation which has taken place, must have been about 600 feet.

As regards the height of the Kaimur scarp, this now is about 2,000 feet above the sea, the highest peak on the main scarp, opposite the southerly bend of the Son being 2,310 feet, and on the Gidela outlier 2,354 feet. The Kaimur range being broader and more plateau-like than the narrow crest of the basal quartzite ridge has probably been lowered in a less degree by denudation, and the present difference in elevation—739 feet—is more than the difference at the commencement of the last period of uplift. From this we see that the Kaimur scarp must then have been in existence, but the highest points probably did not rise more than 500 feet above the level of the Son valley, while the depressions must have descended nearly to its level. Instead of a continuous barrier there must have been consequently a series of low hills with broad, open, easily traversed gaps between them.

Recent erosion in stream channels.

It has been stated that the present is a period of repose and of little or no change in the drainage channels. On the whole this is true and the broad plains in the Son valley show that it must have been absolutely true for a long period. The very last change in the levels of the region seems, however, to have been one of elevation. In the Mirzapur district the Son is bordered by a tract of lowland, a river terrace, cut down to a level of about 30 feet below the general level of the plain of recent deposits. Up stream the depression of this terrace and its width diminish, till in Rewah territory it disappears. In this terrace the actual bed of the Son is depressed and

the depression continues right through Rewah territory and up all the tributaries. Everywhere in fact the plains of recent deposits are cut by deeply sunk drainage channels, and everywhere these are seen to be cutting back into the recent deposits, which evidently formed during a period when the action of the streams was different to what it now is.

Possibly due to human agency.

This universal evidence of erosion points to a last slight movement of elevation, but need not necessarily be attributed to that cause. It is doubtless closely related to the change, whether of elevation or climate, which has led the Ganges and its tributaries to cut down into their deposits and form the *khudis* land of the plains, and in the area now being dealt with it is at least as likely that the change is due to the extensive clearing of forests which has taken place since the advent of man as to a general movement of elevation.

CHAPTER IV.—THE ROCKS OF BIJAWAR TYPE.

PETROGRAPHICAL NOTES.

(E. VREDENBURG.)

SECTION I.—INTRODUCTION.

The notes which form the following chapter were not intended for publication in the shape in which they appear here. They are merely extracts from my progress report of 1896-97. During that camping season, I crossed several times the outcrop of the Bijawars, and I had occasion to see them also when tracing the boundaries of some of the newer systems with which they come into contact. The materials, both petrological and stratigraphical, are insufficient to justify any critical examination, and the study which I made of them was solely intended as a foundation for systematic work; but since then I have had no further opportunity of visiting any more rocks of that system. The following notes cannot therefore contain much that is of general interest, but it is hoped that even in this unfinished form they may be of use to future observers.

In travelling across the country represented on map 476, from south to north, it appeared to me that the structure is that of a syncline, for the same rocks occur in the neighbourhood of the northern and of the southern boundaries, while the central portion is occupied by slates of a different type.

The rocks are generally much more schistose towards the southern than towards the northern boundary.

Basal quartzite.

The bottom bed, sometimes visible along the southern boundary, is a very schistose quartzite occasionally rendered conglomeratic by pebbles of vein-quartz. Resting upon it are slates, interbedded with limestones, chlorite-schists, and lavas; the lavas are absent from the portion of the southern outcrop of this stage examined in map 476, but this may be a local peculiarity due to the irregular distribution of these rocks. These slates are overlaid by runs of jasper often ferruginous and

frequently interbedded with slates of various colours, limestones and thick beds of lava.

This lower stage was termed by Mr. Medlicott the "Agori division," but he regarded it as an upper horizon. Its repetition along the northern and southern boundaries with essentially the same characters make it more probable, however, that the slates situated between these two runs belong to a higher stage, the structure being mainly that of a syncline ; these slates are usually interbedded with a large proportion of fine-grained impure sandstones and never contain any jasper or lava.

In the most western part of the district which I visited, the Bijawar outcrop becomes much narrower, and it may be fairly assumed that only the lower part of the system is represented there. The fact that the entire width of the western outcrop consists of rocks typical of the "Agori stage," lends some support to the above conclusion. But it must be admitted also that a similar distribution might result from the "Agori stage" resting unconformably upon a still older system, a view which was suggested, in fact, by Mr. Medlicott, and has been adopted in the Manual of the Geology of India.

It would require a detailed survey of a large portion of the outcrop in order to obtain any degree of certainty as to its conformation : the structure above suggested is therefore only conjectural. A number of specimens, however, were collected, and these form the subject of the following notes.

SECTION II.—SEDIMENTARY ROCKS.

a.—Sandstones and quartzites.

The quartzite forming the bottom rock along the southern boundary, south of Chingo, specimen $\frac{11}{802}$, is a remarkable example of a veritable quartz-schist in which the schistosity is almost entirely due to the quartz itself, for the rock contains very little else than this mineral. In the hand-specimen it is pure-white in colour, and it is very fissile along the

Quartz-schist.

planes of cleavage. Under the microscope it is seen that only the centres of the quartz-grains subsist; these are greatly elongated in the direction of the cleavage and show considerable strain-shadows. The outer portion of the grains is broken into a fine quartz-mosaic that cements the fragments together. Some flakes of white mica are visible, also lying in the direction of cleavage, but in such a granulated rock it is impossible to say whether it is an original constituent, or whether it may not be a secondary transformation of felspathic materials which may have been originally contained in the rock.

Agori quartzites.

The quartzites obtained from the northern outcrop of the Agori band form a great contrast with the rock just described on account of their much less metamorphosed character. The coarsest grained is specimen $\frac{11}{783}$ which was collected north of the most northern range of Agori quartzites on the road from Khattai to Maoghun, unfortunately not *in situ*. But by comparing it with other specimens which have been found interbedded with the slates, its mineral characters are found to agree completely with them, so that there seems little doubt that it belongs to that same age. In the hand-specimen it is a very hard compact rock containing felspar in such large proportion that it might almost be called an arkose. The felspar gives it a pink colour in the hand-specimen. Under the microscope both the quartz and felspar are seen to form well-rounded grains. The quartz shows strain-shadows much more pronounced than is generally the case with the Vindhyan sandstones and exhibits even a tendency to pass into a mosaic; but it is never granulated as in the rock from the southern boundary. It is true that the rock does contain some portions of quartz-mosaic; only these were originally in this condition in the sand-grains which they constitute and which were probably derived from some granulitic or gneissose rock. The felspar is all microcline. There is a little magnetite and some ferruginous cement between the grains.

The next rock, specimen $\frac{11}{790}$, occurs in the Piperwani river, in this same neighbourhood, just north of the most northern range

of Agori jasper ; it therefore immediately underlies the stage to which this jasper belongs. It is very much finer-grained than $\frac{11}{783}$, but otherwise resembles it in every way except for the much smaller proportion of felspar. The felspar, moreover, differs from that of the preceding rock in so far that it is all plagioclastic.

Other sandstones.

If now we leave the rocks of the Agori stage and turn our attention to the upper division, we shall find that they contain a great many more or less sandy rocks whose appearance differs greatly from that of the types we have just described. The two rocks described from the northern outcrop of the Agori band present all the characters of a quartzite rendered very compact by the secondary growth of quartz. In the higher series the sandstones remain much more friable because the quartz-grains have not become cemented together by this secondary extension, but are more or less separated from one another by micaceous and earthy materials.

The specimen $\frac{11}{784}$ may be taken as a typical example of these rocks. It was collected north of Baghaia or Bagra at a point where the road crosses a small tributary of the Barwar river. The rock has a dull grey colour in the hand-specimen and both quartz and mica may be detected by the unaided eye. When examined under the microscope it shows evidence of strain to a much greater extent than the two sandstones described from the northern band of the Agori stage. The quartz-grains though much smaller show irregular extinction in a much greater degree ; they exhibit a distinct elongation in the direction of schistosity and even show a tendency to break off round the edges. It is probable that a great deal of the finer-grained mosaic constituting the rock is therefore of secondary origin. The quartzite though probably of later date than the above described specimens from the Agori stage is yet much more metamorphosed ; but this is in accordance with its situation farther south, for the amount of disturbance in these rocks gradually increases as we travel away from the northern boundary, the most altered rocks being found at the extreme southern limit.

Fragments of tourmaline.

Age of gneiss.

In addition to quartz the sandstone $\frac{11}{784}$ contains felspar and a great deal of muscovite giving it a distinct schistosity. The mica plates are seen bending round the quartz-grains which shows that they are not of secondary origin. The rock is further remarkable for containing a great many grains of tourmaline. All its constituents are such as might be derived from a gneiss quite similar to that which is found n many neighbouring regions, and we may conclude that the rock from which the Bijawar beds were derived was no other than the gneiss exposed at the present day.

We find all gradations from these impure sandstones down to the finest slates. Some of those that have been more particularly studied present many points resembling the specimen $\frac{11}{784}$. They are principally from the hilly region where the Agori jaspers and lavas are profusely exposed. But as it has not been possible to unravel the distribution of the folds, it is not possible to tell whether the places where the rocks were collected are portions of synclines or anticlines, and we cannot tell whether they belong to the beds immediately overlying or underlying the principal jasper horizon or to those associated with that horizon.

Deori.

The specimen $\frac{11}{799}$ was collected a short way north-east of Deori. The slates accompanying it have the same facies as those associated with the specimen $\frac{11}{784}$ from Bagra and probably belong also to the upper stage. The sandstone $\frac{11}{799}$ is very similar to $\frac{11}{784}$ in the hand-specimen, only with a more earthy appearance. The same also holds good for the microscopical section which is very similar : the quartz-grains are about the same size and show the same strain-shadows, but they are separated by a greater proportion of fine-grained material much of which appears to be decomposed mica. There is magnetite together with rusty ferruginous products which may be products of superficial weathering. The rock also contains a great deal of felspar which is somewhat altered.

The specimen $\frac{11}{749}$ is a very fine quartzite collected from a point west of Chatni and north of one of the most important outcrops of lava. In the hand-specimen it is a compact pale-grey rock of fresh appearance but with distinct cleavage. Under the microscope it appears composed of very small sand-grains with much intervening micaceous mineral. The sand-grains are mostly quartz exhibiting strain-shadows to a marked extent. Scattered through them are a few grains of felspar. The micaceous minerals are white mica, very much altered, and some secondary chlorite.

Chatni.

This fine sandstone grades imperceptibly into slates such as specimen $\frac{11}{750}$. In the hand-specimen it is a compact light-grey slate with very regular cleavage. Under the microscope it is seen to consist essentially of the same minerals as $\frac{11}{749}$, quartz and mica, only it is extremely fine-grained and the proportion of mica is much greater. The quartz-grains have their longer dimension lying in the direction of the cleavage. Whenever the principal section of one of the crossed Nicols is parallel to the cleavage, the section extinguishes entirely with the exception of the quartz-grains, thus showing the perfect parallelism of all the micaceous constituents which give the rock its regular cleavage. The micaceous mineral consists largely of white mica, muscovite or sericite polarising in brilliant colours. There is in addition a fair proportion of chlorite.

Finer-grained rocks.

The rock $\frac{11}{791}$ is so fine-grained that it should be classed as a slate, the component grains being quite invisible without the aid of a lens. But as the microscope shows it to consist almost entirely of derived fragments of quartz, it is properly grouped with the foregoing sandstones. It is in fact a sandstone on a microscopic scale; the quartz particles have none of the appearance of secondary crystallisation as is the case with the jaspers. The specimens were collected in the river that flows through Chakari a short way west of the Vindhyan boundary. The

Quartz-slate.

Chakari.

beds dip 15° W. of S. at 85° and are very much contorted as may be seen even in the hand-specimen. The rock has a light silvery blue colour with bright ferruginous ruddy stains in irregular bands. Under the microscope the rock is seen to consist of exceedingly minute sand particles consisting mainly of quartz with a few equally small grains of tourmaline. There are many minute flakes of brightly polarising white or pale-green mica. The section also shows white opaque patches which probably consist of clay or kaolin.

b.—Slates.

By the addition of a gradually increasing proportion of micaceous minerals to these fine-grained sandstones, we obtain the rocks that constitute the greatest part of the Bijawar slates to which class belongs the specimen $\frac{11}{750}$ which has just been mentioned.

Purple slates; resemblance to the Red Shales.

Slates of a deep purple colour are very frequent especially in the horizon where jasper bands and lava-flows are most numerous. These purple slates completely resemble the red shales. The only difference that can be made out is a slight difference in colour. The red shales are of a more decided purple colour, while the similar Bijawar shales are somewhat tinted with a shade of steel blue. The difference is a slight one, but it is quite distinct when specimens of the two rocks are brought close together. It is not possible to make out the exact nature of the pigment as it is extremely fine-grained and quite opaque. It is no doubt of a ferruginous nature and this causes the high specific gravity of these rocks. The microscopic sections are rendered opaque to a great extent by this ferruginous material, which lies between the other minerals spread along the direction of cleavage. Besides this ferruginous material, there are small grains of quartz and flakes of mica, the latter mineral being the more abundant of the two. It occurs in greatly crumpled bundles polarising in high colours.

Calcareous Slates.

There are some highly calcareous slates which are common amongst the volcanic strata to be mentioned hereafter.

Resemblance to Porcellanite beds of Lower Vindhyans.

The Agori stage of the Bijawars often contains bands of siliceous rock in which the particles of quartz are as fine as or even finer than in the finest-grained rocks hitherto mentioned, but owing to the absence or smaller proportion of associated mica, the rocks do not exhibit any distinct cleavage. They bear a remarkable outward resemblance to the Vindhyan porcellanites. It will be mentioned when discussing this latter formation that rocks of different origin could in the course of recrystallization assume a very similar appearance. Thus a fine silt consisting mainly of finely divided quartz, a siliceous ooze originally consisting of particles of colloid silica, a band of chert, or an acid volcanic ash might finally become very similar in outward appearance if devitrification and recrystallization have been acting long enough. In the case of these Bijawar porcellanites their complete gradation into the fine slates indicates that they are merely a variety of these rocks resulting from a slightly different mineralogical composition. The minute quartz particles being more abundant, while the micaceous minerals are fewer or wanting, so that the rock does not possess any distinct schistosity. The conclusion drawn from the mode of occurrence of the rocks is confirmed by their microscopical examination. The rock is much finer-grained than any of the Vindhyan porcellanite slides which I have examined (with the exception of slide 1890, specimen $\frac{10}{703}$, collected in the Samdin river); it always contains a fair quantity of minute micaceous flakes which have every appearance of being of derived character; it never shows any of the tuffaceous characters exhibited by the Vindhyan specimens.

The peculiar rhombohedral jointing of the Vindhyan porcellanites is very imperfectly developed or entirely wanting in these Bijawar varieties. In place of it we find the rock irregularly cracked and faulted in such a manner as to render it almost impossible to obtain specimens. In addition to this, the rock may have a tendency to

cleave. The lustre in a hand-specimen is dull and stony. The rock never shows the glossy fracture and semi-transparency so frequent in the Vindhyan varieties. Yet none of these differences are very conspicuous, the resemblance, especially in the field, being sufficiently pronounced to be very confusing. An instance of a very misleading exposure has been mentioned in the stratigraphical portion of this Memoir, with respect to the beds seen at the bend of the Son, opposite Gurdah.

Should any doubt exist as to the correctness of attributing these rocks to the Bijawars, it could not be better dispelled than by examining specimen $\frac{11}{786}$. Here we have a stratum which is not more than one centimetre in thickness, interbedded with purple shales of the most typical Bijawar type. It was collected amongst the hills immediately north of Jungel amongst the purple slates described above. The narrow siliceous band is of a dark grey colour differing in that respect from the bluish rocks of Gurdah. But in all other physical characters it is quite similar, and the similarity subsists under the microscope.

c.—Jaspers.

In some of these porcellanoid slates, much of the groundmass has the appearance of devitrified colloid silica. If we imagine now a siliceous rock without any of the quartz-grains or mica flakes of the porcellanic slates, but offering nothing but a uniform extremely fine mosaic of quartz or chalcedony, we shall obtain the jaspers that form such a characteristic feature of the Agori stage and which form conspicuous beds in many of the "Transition" systems of India, such as the Bijawars of Bundelkhand, the Gwalior, or the Dharwar series. They have frequently been noticed as pebbles in Vindhyan conglomerates that have been derived from those older systems, the bright-red colour which they often assume making them specially conspicuous.

Hematitic rocks.

The rock is usually of a translucent bluish-grey shade which is lighter or darker according to different specimens; the structure appears entirely homogene-

ous to the unaided eye. It is frequently and characteristically striped with bands of varying width of a bright-red colour caused by minute particles of hematite. Examined with a high power of the microscope, these hematite particles are seen to be scattered through a very minute and regular mosaic of quartz or chalcedony. They appear by transmitted light of a deep blood-red colour and exhibit perfect crystalline outlines. Larger grains of quartz are visible only as secondary infillings of cracks. Sometimes the proportion of hematite becomes so great that the ferruginous bands consist almost entirely of this mineral. They lose then their red colour and appear black or metallic and the rock becomes an iron ore.

Curious structure perhaps organic.

A remarkable microscopic structure is exhibited by one of these rocks (spec. $\frac{11}{788}$). It was collected on the banks of the Son at Agori Khas, the jasper being intercalated with limestone. The hematite particles are disposed throughout the chalcedonic groundmass in the shape of minute hollow spheres or ellipsoids. These are not of the nature of spherulites, for the hematite grains that constitute them are not in contact with one another and are exceedingly small compared with the dimensions of these hollow spheres. In those parts of the slide where the structure is best exhibited, there are two concentric envelopes of hematite dust, and between them is a transparent ring showing the presence of a hollow sphere of silica. These little bodies are distributed all over the slide quite irrespective of the proportion of hematite dust. In those portions of the slide where the proportion of hematite is small they become less clearly delineated, while they disappear naturally when this mineral becomes so abundant as to render the section opaque. It is where the hematite is abundant, without however interfering with the transparency of the slide, that the structure is best visible and the two concentric envelopes most clearly exhibited. It is possible that the structure may have been originally organic.

Rocks near "Belawa peak."

Other rocks which also present a jaspidious and banded appearance in the hand-specimen contain magnetite instead of hematite. Such is specimen $\frac{11}{771}$

collected from an important stratum occurring W.-N.-W. of Belawa peak. Its colour is a pale shade of grey or greenish grey; the magnetite is scattered in little octahedra which give a peculiar sparkling lustre to the hand-specimen. Under the microscope the shapes of the magnetite crystals appear very perfect so that the crystals must be of secondary origin. The specific gravity is 2·88. The true nature of the rock is difficult to decide: it is not a lava, yet it always occurs in conjunction with volcanic rocks. The following succession of strata, proceeding from north to south, occurs in the neighbourhood of Belawa peak where the specimen was collected :—

A. Ordinary grey-coloured slates of the Bijawars.
B. Fine-grained diabase ($\frac{11}{761}$).
C. Jaspidious rock with magnetite ($\frac{11}{771}$).
D. Talc schist with crystals of pyrites ($\frac{11}{755}$).
E. Chlorite schists containing bands of diabase ($\frac{11}{759}$) and lenticular or elongated masses of limestone.
F. Limestone.
G. Chlorite schists, highly calcareous, and interbedded with diabases and melaphyres.
H. Slates similar to A.

The width of this outcrop is over 1,000 feet. From Belawa peak eastwards it may be followed as far as Naogai without any great alteration, and from this again up to Girwi, where however its thickness has diminished. Neither the most western nor the most eastern points observed represent the termination of the band. In the above series all the rocks included between the slates A and H are undoubtedly volcanic, with the exception of the variable limestone F, and this peculiar jasper C. Yet this jasper is so intimately associated with the volcanic rocks that there probably does exist some connection between them. The chloritic limestones are of the nature of volcanic tuffs. These peculiar jaspers may have been of somewhat the same nature as the typical Agori jaspers, but mixed with a certain amount of volcanic dust or other volcanic material.

d.—Limestones.

It seems doubtful how far any of the Bijawar limestones are truly of derived origin, that is, derived from the desintegration or solution and the re-deposition, or re-precipitation of previously existing limestones. Rocks of this nature occur sparingly in the underlying gneiss. They may be the accumulated remains of calcareous organisms, of which all trace has been obliterated, or they may have resulted purely from chemical precipitation, being derived from the supersaturated calcareous springs that usually accompany volcanic eruptions, and would be therefore related to travertine. Their close association with the volcanic rocks renders this interpretation very probable. They are frequently so rich in chlorite that they become chlorite-schists. The latter are in all probability metamorphosed tuffs. The most important runs of limestone are generally interbedded with these chlorite schists. Sometimes the limestones are not in direct contact with any volcanic rock, as in the case of the strata interbedded with jasper at Agori. Wherever volcanic rocks are totally absent, as in the region examined about Chingo, there is also a complete absence of limestone.

They frequently form small elongated lenticular masses varying in dimensions from a few inches to several feet, intercalated between the divisional planes of the calcareous chlorite schists. At other times they form thick continuous bands. One of the most important amongst these may be followed continuously from Urangi up to Kosai. It has already been mentioned in connection with the description of the Vindhyans. It is quite possible that several of the outcrops which run in parallel bands are repetitions of the same rock due to folding, but a detailed survey would be necessary to decide that point.

When it forms lenticular masses amongst the chlorite schists, the limestone is frequently somewhat fine-grained and is striped in a direction parallel with the strike of the schists, showing bands of white pink-grey or greenish and bluish tinge (specimen $\frac{11}{766}$ and $\frac{11}{764}$). Sometimes it is coarser grained and saccharoid (specimen $\frac{11}{767}$).

The rock forming the thick continuous bands is usually highly crystalline and much coarser-grained than any of the Vindhyan limestones. They are nearly always conspicuously striped or mottled (see specimens $\frac{11}{768}$, $\frac{11}{765}$).

The limestone interbedded with the red jasper at Agori Khas (spec. $\frac{11}{787}$) shares the red tint of the jasper itself, similarly due to the presence of hematite which gives the rock a very high density, 2·91.

SECTION III.—VOLCANIC ROCKS.

a.—Stratigraphy.

The most characteristic members of the Bijawars are the basic volcanic rocks.

In the Son region they are confined to the Agori stage, their greatest development coinciding with the horizon richest in jasper. But they are also frequently interbedded with the strata that appear to underlie that horizon. Where the Bijawar outcrop is broadest, they are absent from the central portion of the outcrop, which probably represents a higher horizon. In map 481, where strata presumed to belong to the Agori stage reappear along the southern boundary, owing to the synclinal nature of the Bijawar outcrop, no volcanic beds are seen to occur at least in the portion which I have examined. This absence may be due to the irregular distribution of the rocks: the outcrop of the Bijawars is here very wide, as much as twenty-five miles, and, taking into account the amount of compression which they have suffered, this width answers perhaps to as much as three or four times the original distance at which the beds were deposited, and this leaves plenty of room for horizontal variations.

West of the Gopat where the Bijawar outcrop becomes much narrower, volcanic rocks are freely developed in the neighbourhood of the southern boundary, just as much as near the northern one, and in fact throughout the whole width of the outcrop.

Eastwards of the region which I examined in map 481 of Rewah,

and in which the southern outcrop of the Agori stage contains no volcanic rocks, I have had no opportunity to examine the southern portion of the Bijawars. But the description given in the Manual, of the Rer section (1st edition, page 35, 2nd edition, page 56) leads one to believe that here again the Agori stage stretches right across the outcrop, and that volcanic rocks have reappeared.

Absence of dykes.

Owing to the disturbed condition of the Bijawars, it is sometimes difficult to decide whether these igneous rocks are interbedded or intruded. If any considerable proportion of them were of an intrusive character, we might expect to find a profusion of dykes in the immediately adjoining archæan gneiss. This not being the case, it is probable that most of the basic rocks found in the Bijawars of the Son region are in reality interbedded flows, but the examination of neither gneiss nor Bijawar has been complete enough to make any decisive affirmation. In a great many cases, however, there is no doubt as to the crystalline lavas being interbedded.

The underlying archæan series does contain, it is true, a profusion of basic dykes, but these are of archæan age and differ in their characteristics from those of the Bijawars. Hypersthene and garnet which occur in the archæan are not to be found in the Bijawar rocks; while the reverse is the case with pyrites. Leucoxene and chlorite are extremely abundant in the Bijawars, but seldom met with in the archæan. It is important to draw this distinction, because as there has been sometimes some confusion in determining the exact boundary of the Bijawars, rocks really belonging to the gneiss have sometimes been reckoned as part of the Bijawars. Hence by studying the specimens preserved in the Museum, one might be led to believe that some of the basic rocks in the two formations are identical.

Basic volcanic rocks are never absent from the northern portion of the Bijawar outcrop throughout the whole length of the Son outcrop far beyond the limits of my own observations: the collection contains specimens from localities as far west as Hardi, beyond which point the Bijawars are exposed only for a short distance. My

own observations extend principally over the northern portion of map 481, and the southern portion of map 480.

Along the hilly region which extends south of the most northern range of jaspers, there are two great runs of volcanic rocks. The structure appears to be such as is diagrammatically represented in the following section :

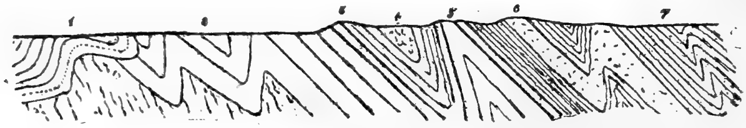


Fig. 5.

1. Bed of the Son with the Vindhyans.
2. Alluvial plain of the Son with the lowermost beds of the Bijawars : slates interbedded with sandstones, limestones and lava-flows.
3. The most northern range of the hematitic Agori jasper.
4. The longitudinal valley of Sirwa and Piperwani largely occupied by lava-flows and chlorite schists.
5. The range containing Cheropahar hill, consisting largely of jasper, often in a brecciated condition, with siliceous slates and slaty quartzites.
6. The range containing Belawa peak consisting mainly of volcanic rocks.
7. The broad undulating plain drained by the Gotun river ; it lies along the central portion of the Bijawar syncline and the beds belong to the upper members of that series.

The most southern band of volcanic rocks, that which runs through Belawa peak, has already been alluded to in connection with some peculiar jaspers that it contains (see above, page 68). The next band to the north of it has been examined with less detail ; but it contains exactly the same varieties of rock and may be regarded with a fair degree of probability as its repetition. North of the most northern range of the Agori jaspers we get the slates underlying that horizon, and here again we frequently meet with interbedded lavas. Of all the rocks of this district the Bijawar jaspers are those that most successfully resist denudation. If a wide band of volcanic rocks

occurs between two runs of jasper, it forms an area of lower ground, as in the longitudinal valley of Piperwani. But if these same rocks are bounded on one side by nothing but the softer slates, then they themselves rise into ranges comparable in height with those formed by the jaspers, as in the case of the range which contains Belawa peak.

b.—Petrography.

Classification.

All these rocks may be divided into two classes; those that are properly speaking igneous, and others which partake of a sedimentary character and probably of a tuffaceous nature.

The rocks of the first class are principally uralite-diabases, and altered basalts or melaphyres. Some of them are somewhat coarse-grained like one of the specimens from Bhanni ($\frac{10}{696}$) described by Mr. Oldham as obtained from a dyke; and we get every gradation up to rocks which originally must have contained a large proportion of glassy magma, such as $\frac{11}{753}$ from Dholki. All the volcanic rocks from the Son outcrop of the Bijawars are, without exception, altered to a considerable extent.

Metamorphism.

Unaltered olivine has not been observed. Augite was found in two instances only ($\frac{11}{769}$ and $\frac{11}{754}$) and is then of the pale-coloured variety, poor in iron. In every other instance it is entirely altered to an extremely pleochroic uralite, while at other times, especially in the base of some of the finer-grained rocks, it appears to have united with part of the substance of the felspars to form needles of paler hornblende. The felspar is universally saussuritised to a considerable extent. Ilmenite has often entirely changed to leucoxene. The secondary hornblende itself is often further altered to chlorite and epidote. In fact epidote and chlorite are abundantly developed in all these rocks; chlorite is never absent and contributes more than any other mineral in communicating to them their characteristic green colouration.

In addition to these chemical changes the rocks everywhere exhibit the effects of dynamical action which was, in fact, the original cause of most of these chemical changes.

All these rocks having been equally subjected to great compression and all of them altered in very much the same manner, it follows that the differences in specific gravity which in fresh specimens distinguish the more glassy basalts from the coarser porphyries have become obliterated. Hence there is not much variation in specific gravity, the mean density of all the specimens observed, leaving out two rocks of perhaps less basic tendencies, is 2·98. The extreme limits observed are within 2·9 to 3·1.

It would be interesting to study a series illustrating their gradual transformation from the unaltered rocks; but such a collection could not be obtained in the region which I visited, as all these rocks are in advanced stages of metamorphism. In other parts of India, however, the Bijawars have been much less disturbed, and they furnish specimens which give some idea of appearance of these rocks in their original condition.

Rocks from Bundelkhand.

The collection in the Museum contains several rocks from Bundelkhand which answer to this description. They have been alluded to by Mr. Holland (Records, Vol. XXX, page 37), and may be briefly referred to in the present instance. Such are the specimens $\frac{5}{8}$ and $\frac{5}{10}$, ophitic dolerites, consisting of labradorite, ordinary brown augite, and ilmenite, with some biotite, micropegmatite and serpentinized olivine. In the hand-specimen the rocks have the appearance of coarse basalts of the freshest type without any of that green tinge which characterises the metamorphosed material. The specific gravity of $\frac{5}{8}$ is 3·04; while $\frac{5}{10}$ consists of several fragments giving an average density of 3·09. With the exception of the serpentinized olivine, all the minerals are absolutely unaltered. The freshness of the specimens is surprising considering their antiquity. In searching through the collection I have succeeded, however, in obtaining some intermediate stages, by no means a complete series, but yet sufficient to indicate that a

gradation does exist, and that if the region were surveyed with that object a series of complete gradations could be obtained.

Various stages of metamorphism.

The first stage of alteration that has been observed is illustrated by the specimen $\frac{5}{22}$ collected in Bundelkhand from a hill north-west of the road from Chowkee to Dergrah. It is coarser-grained than the two rocks just described. It resembles them in the hand-specimen, but it already shows a faint greenish tinge. Its specific gravity is 2·97. It consists of the same minerals, but one of them at least is distinctly altered: this is the augite which shows initial stages of uralitisation. It was originally a brown augite similar to that of the unaltered dolerites, but much of it is now coloured green in irregular patches caused by numerous particles of hornblende disseminated throughout its mass, and in a few places the transformation is complete. Where the mineral has not been changed to hornblende it is striated and clouded and stained with ferruginous products. The felspar is altered in the micropegmatitic intergrowths and sometimes in patches through the crystals, but on the whole it is as fresh and unaltered as in many much more recent rocks. The ilmenite shows no signs of any change.

Metamorphism has proceeded to a far greater extent in the specimen $\frac{5}{9}$. It is interesting as being derived from the same locality as the unaltered dolerites $\frac{5}{8}$ and $\frac{5}{10}$, showing that rocks in distinctly different stages of metamorphism occur at no great distances from one another. In the hand-specimen this rock has a decided resemblance to some of the Son region specimens poorer in chlorite. Its colour is already such as to justify the name of "greenstone." The rock is finer-grained than those last described. The proportion of hornblende is much greater, and some of it occurs in fibrous forms. Chlorite makes its appearance. Yet there is still a great deal of augite; but the alteration of the felspars has proceeded to a considerable extent.

Next to this rock we may class $\frac{55}{34}$, a contemporaneous lava

collected by Mr. Wilson in the Bijawars, north of Surajpuar. It is one of the rocks mentioned by Mr. Holland in the Records, Vol. XXX, page 37. In this rock the augites and felspars seem to have crystallised to some extent simultaneously, ilmenite and micropegmatite enclosing them both. The saussuritisation of the felspars is here all but complete. The augites are largely altered to green pleochroic uralite in a curiously irregular manner: one crystal is still unchanged while the next one is entirely altered to hornblende; or else one end of the crystal is augite, the other end uralite. Sometimes the change seems to take place along the striations in the augite. In many cases the transformation is seen starting from the outside; but in one case also the centre of an augite crystal is changed to hornblende. The hornblende is in crystallographic continuity with the augite from which it is derived. There is also some fibrous hornblende and some chlorite. The ilmenite is still unaltered.

$\frac{5}{13}$ is a dyke of uralite diabase from the gneiss at Barow. As it has the character of the Bijawar lavas, it may be regarded as belonging to the same period. Here the augite is entirely changed into a pale uralite, which may reproduce the structure of the original crystal or else forms a confused felted fibrous aggregate. Only isolated irregular traces remain of the original augite. The felspar is altered to saussurite to such an extent that in many parts of the slide the structure is completely obscured; yet in other portions it has retained its clearness. Another of the minerals which in the previous rocks was little altered here shows conspicuous metamorphism: this is ilmenite now largely altered to leucoxene.

Son region.

With the next rock $\frac{32}{126}$, we enter the Son region. The rock was collected by Mr. Hackett at Hardi at the western termination of the Son outcrop of the Bijawars. Here again some of the augite substance still remains as such, but in most cases it is much obscured with iron oxides and altered into a confused aggregate of decomposition

products so fine-grained as to be difficult to identify. The felspar is almost completely saussuritised; leucoxene is largely developed. Another secondary mineral here makes its appearance, which will be found always present in the rocks about to be described: this is epidote which, in the present instance, may be observed forming large granular aggregates. The rock, however, shows none of the deformation and crushing of minerals which is so often observed in other parts of the Son region. At this western extremity of their outcrop the Bijawars are probably less disturbed.

Nearly all the above-mentioned specimens contain micrographic intergrowths of quartz and felspar.

The series which we have just considered is far too incomplete to allow a detailed study of the manner in which the gradual metamorphism of the different minerals is accomplished, but it may serve to give some idea as to the original condition of the rocks which we are about to review, and also to show that the lavas occurring in these two separate areas of the Bijawars belong to the same class of rock.

All the rocks which I have collected are considerably altered: the micropegmatite, if it ever existed, has entirely disappeared. Except in two specimens, the alteration of augite to hornblende is complete. The change of ilmenite into leucoxene has proceeded so far that frequently nothing remains of the original mineral. In addition to these chemical changes the rocks exhibit conditions of strain and crushing of the minerals. Epidote and chlorite are universally present in large quantity, the latter mineral giving the rocks their characteristic colour. Calcite is often largely developed.

All the specimens contain crystals of secondary pyrites which are conspicuous in the hand-specimen, but generally break off during the preparation of microscopic sections.

Referring to the diagrammatic section above represented (Fig. 5),

Rocks at Girwi.

we may first review the rocks composing the more southern of the two main outcrops (6 in diagram).

Some of the rocks contained in this outcrop have already been noticed (see above, page 40), and it was mentioned that the outcrop was followed for a considerable distance, from Naogai to the west, up to Girwi to the east, and that it extends beyond either point.

At Girwi the rocks dip at a high angle in a direction E. of S.

The most southern rocks of this outcrop are slates of the usual Bijawar types. Immediately north of them comes a lava-flow, No. $\frac{11}{770}$; it is a fine-grained greenstone exhibiting distinct schistosity in the hand-specimen. The rock differs widely from the comparatively unaltered types hitherto mentioned, as it affords evidence of considerable crushing. In its present condition it consists principally of hornblende and felspar, together with leucoxene, chlorite and epidote. The hornblende is to a large extent fibrous, giving the rock its imperfect schistosity. The felspar shows considerable strain-shadows, and the long-shaped crystals are generally broken up into smaller grains. Those that still retain any indication of their original shape, show by their narrow dimensions that the rock was originally a fine-grained dolerite or coarse basalt. The epidote and chlorite which occur in close association probably represent a further stage of alteration of the hornblende. The specific gravity of the rock is 2·97.

Signs of dynamic metamorphism.

The two next rocks, $\frac{11}{774}$ and $\frac{11}{778}$, have a decidedly fragmentary and bedded appearance. $\frac{11}{774}$ in particular weathers in a manner simulating a coarse conglomerate, the pebbles, however, being quite similar to the matrix. The rocks of this exposure are so highly disturbed that it is difficult to tell whether the structure is an original one, or whether it is due to subsequent brecciation attendant upon folding.

In the specimen $\frac{11}{774}$ where the fragments are sufficiently small to allow of a number of them appearing in the same microscope section, they often show great differences in coarseness of grain, which may be taken as a proof of the disconnected and clastic nature of the rock. The best preserved minerals are the felspars.

In some of the coarser-grained fragments they occur in long lath-shaped crystals exhibiting well marked twin lamellæ and quite unaltered. In finer-grained fragments their shapes are greatly or entirely obliterated by innumerable matted minute prisms of pale green hornblende, representing the original augite of the base, now entirely metamorphosed. It is not improbable that some of the substance of the felspar has contributed towards the formation of this variety of hornblende. Some of the rock fragments are almost obscured by iron ores in small grains as is often seen in a fine-grained basalt, or else finely disseminated ilmenite is entirely altered to leucoxene. Considerable quantities of epidote and chlorite occur as usual. Here and there may be seen larger crystals of pleochroic uralite, indicating the previous existence of porphyritic augites. Sometimes they are twinned and their substance is compact, but often they become fibrous and are frayed and torn along the direction of bedding, showing that although the clastic structure is original the rock has nevertheless been subjected to considerable motion since its consolidation.

Uralite with the shape of augite.

The clastic or brecciated nature of the rock $\frac{11}{778}$ is very conspicuous in the hand-specimen, but is not visible in the microscopic section on account of the large size of the fragments. It shows under the microscope a very fine-grained basaltic groundmass through which are scattered some narrow porphyritic felspars, as much as half a millimetre long and arranged along the direction of flow, and large beautiful pleochroic uralites, some of which are over a millimetre in diameter. These reproduce accurately the shape of the original augite and even such details as partial corrosion by the fluid magma, and at the same time indicate the change in mineralogical composition mentioned by Rosenbusch and other authors as frequently accompanying the uralitisation of augite: the large crystals are sometimes surrounded by a fringe of calcite and chlorite, and in the interior of their mass patches of chlorite with epidote crystals are

sometimes observed. In other places we find no more trace of either pyroxene or amphibole, only large crystals of epidote surrounded by chlorite.

The characters of the groundmass are like those observed in the fragments that constitute $\frac{11}{774}$. The pyroxene has combined with some of the felspar substance producing a closely matted mass of minute actinolitic crystals which even spread into the porphyritic felspars and obliterate the sharpness of their outlines. The flow structure is well indicated by aggregates and strings of ilmenite and leucoxene.

Metamorphosed tuffs.

North of this rock comes a calcareous schist of the same colour (specimen $\frac{11}{777}$). It is a limestone containing a considerable proportion of chlorite and epidote. These secondary minerals must have been derived from materials similar to some of those contained in the volcanic rocks just described. We may regard these rocks therefore as sediments consisting of finely divided eruptive material, mingled with the calcite which may be itself of volcanic origin.

Further north these strata become interbedded with saccharoid limestones, and then the section is concealed.

Rocks near Belawa peak.

I will now refer again to the list of strata given on page 158, as occurring in the neighbourhood of a hill marked on the map as "Belawa peak." The rocks belong to the same band as those described from Girwi, but the series has acquired more importance and contains some interesting rocks which in the Girwi section are absent or imperfectly exposed.

The most southern rocks belonging to the band G, are analogous to those just described from Girwi; they contain the same dark chlorite schist and the limestone bands. Further north they are interbanded with beds of an igneous nature. These on account of their superior hardness often give rise to hill ranges: such is the case with specimen $\frac{11}{759}$, collected at the summit of the peak occurring north of Jagraowa This rock presents some curious peculiarities. It shows very distinctly in the hand-specimen the long prismatic

felspars that often attain a length of two millimetres. Veins and patches of pink calcite are also conspicuous. Here again, in the microscopic section, the broken condition of the felspars is such as to cause doubt as to whether this rock was originally of the nature of a tuff or a lava. In this case, however, it often appears that the felspar crystals have been broken since the original consolidation of the rock, for the fragments lying side by side ran frequently be referred to one crystal. One crystal, originally a continuous prism two millimetres long, is now broken into as many as sixteen fragments. At other times the crystals have been shivered into a confuse mosaic. This is the only unaltered mineral that remains in this rock, of which, however, it makes up by far the largest proportion. The rock differs from all the other specimens in containing neither hornblende nor leucoxene, nor epidote. The spaces between the felspar fragments are occupied by nothing but chlorite, calcite, and some small grains of iron ore, probably all of secondary origin. The rock must have been originally less basic than the usual type. The specific gravity is decidedly below the average, being only 2·83. Whatever may be the origin of this calcite and chlorite, they have by their yielding nature protected from the effects of dynamo metamorphism the felspar fragments and aggregates which they isolate from one another. This mineral shows the broad twin lamellæ of labradorite, and although broken, it is fresh and unaltered.

North of this rock we get more of the dark chloriteschists, then a paler variety D with large well-shaped crystal of pyrites (specimen $\frac{11}{755}$). Next comes the peculiar green jasper C, described on page 68, possibly also of tuffaceous nature. Lastly we find a bed of fine-grained compact green diabase (specimen $\frac{11}{761}$) resting upon the slates A. In the field this rock has a jointed appearance and weathers into spheroidal masses very much after the manner of a basalt. It has a specific gravity of 3·04. Under the microscope this rock exhibits one of the most extreme types of alteration. A few fragments of the prismatic felspars are sufficiently well preserved to show by their small dimensions that the original rock

was fine-grained, and nearer a basalt than a dolerite. These are the only unaltered minerals. The section shows nothing but a confused mass of irregular felspar granules, uralitic and actinolitic hornblende, epidote chlorite and leucoxene, and even quartz, all of them of secondary origin with the exception of the felspathic groundmass which consists of the fragments of the original prisms. There are some curious pseudomorphs of a mineral, which, judging from the shape of the sections, appears to have been olivine. The original substance is replaced almost entirely by epidote, the remainder being occupied by chlorite. The epidote crystals have begun growing inwards from the boundaries of the crystal, producing an appearance recalling that of the chondri in meteorites.

c.—Coarser-grained lava. Diabase.

We may next review some of the volcanic rocks collected from other exposures. They are all closely related to those just described, but present nevertheless some interesting variations. They may be conveniently divided into coarser-grained diabases, and finer-grained melaphyres.

Amongst the coarser-grained varieties, I shall first mention specimen $\frac{11}{769}$, the only diabase of this district in which augite has been observed. It occurs north of Jungel interbedded with the purple slates $\frac{11}{779}$—$\frac{11}{781}$. The diagram Fig. 6 indicates the distribution of the rock.

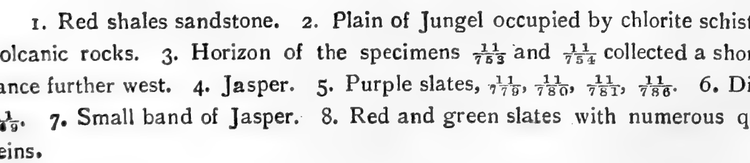


Fig. 6.

1. Red shales sandstone. 2. Plain of Jungel occupied by chlorite schists and volcanic rocks. 3. Horizon of the specimens $\frac{11}{753}$ and $\frac{11}{754}$ collected a short distance further west. 4. Jasper. 5. Purple slates, $\frac{11}{779}$, $\frac{11}{780}$, $\frac{11}{781}$, $\frac{11}{786}$. 6. Diabase $\frac{11}{769}$. 7. Small band of Jasper. 8. Red and green slates with numerous quartz-veins.

In the hand-specimen the rock has a pale green colour. Though it is not very fine-grained, the component minerals are difficult to distinguish because they all possess nearly the same colour. A few specks of pyrites may be recognised. The specific gravity is 2·91. Under the microscope the rock shows an ophitic structure with a tendency to glomeroporphyritic. The augites occupy large areas without proper crystallographic boundaries and are penetrated into by the labradorite prisms. The crystallisation of the felspar had gone on to a considerable extent before that of the augite began. The mineral belongs to the variety known as sahlite, being almost colourless in section and very transparent in the hand-specimen. The cracks and cleavage striations are more developed than is usually the case in recent lavas, but otherwise the mineral is absolutely fresh and unaltered. It seems as though these pale augites are not liable to paramorphic changes in the same measure as the darker, brown varieties. Not only is it the least altered mineral in the rock, but it is the only one unaltered. The felspars are considerably obscured by chlorite, epidote and actinolite which surrounds the crystals, penetrates round their borders or through their cleavage cracks, or form patches in the midst of their mass. The abundance of these secondary minerals attests the former presence of some ferromagnesian minerals other than the large pale augites which evidently contain very little iron.

Unaltered augite.

As a contrast to this rock with its unaltered augite, I may next mention a specimen containing the most typical uralite $\frac{11}{773}$. It was collected north of Sisla Dan and belongs to the more northern of the two bands of volcanic rocks represented on figure 5. The texture exhibits about the same coarseness of grain as in the rock $\frac{11}{769}$ just described, only the hand-specimen presents a mottled appearance owing to the contrast between the dark green silky hornblende and opaque white saussuritised felspar. Idiomorphic crystals of secondary pyrites, cubic in shape, are abundant. The specific gravity is 2·97. Under the microscope the structure appears well preserved,

notwithstanding the alteration of the minerals. The original augites had crystallised at an earlier stage than in $\frac{11}{769}$ for many of them show idiomorphic outlines. Portions of felspar prisms are, however, intergrown with them, showing that crystallisation of the felspar had commenced before that of the augite was completed. This augite is, however, entirely changed to uralite which exhibits the most beautiful pleochroism.

Typical uralite pseudomorphs after augite.

The sharp-angled cleavage with its want of parallelism to the prism faces, so characteristic of uralite, is exhibited in several crystals. The substance of the hornblende is crowded with small inclusions the exact nature of which it is difficult to ascertain. They give the crystals a somewhat clouded appearance. Sometimes the sharp and well-defined edge of the crystal is surrounded by an additional narrow zone of chlorite full of minute actinolitic needles, more or less irregularly oriented. At other times, a fringe of hornblende needles has developed in crystallographic continuity with a grain of uralite producing an additional growth of small prisms projecting into the saussuritised felspar. That they are an additional growth and not the torn edges of the hornblende is made clear in this case owing to the outline of the felspar which can still be clearly followed. The present section shows several instances where this is undoubtedly the true explanation. The felspars exhibit the characters of labradorite, but they are saussuritised to an extent quite comparable with the specimen $\frac{11}{769}$. The usual chlorite-epidote aggregates are typically developed. Ilmenite is mostly altered to leucoxene, but sometimes cores remain of the unaltered mineral.

Secondary growth of hornblende.

This uralite-diabase may be taken as the type of a very large number of Bijawar rocks all presenting almost identical characters. $\frac{10}{696}$, collected by Mr. Oldham at Bhanni, is absolutely identical in section. It is a little coarser grained in the hand-specimen. The specific gravity is the same: 2·97. Such is also $\frac{11}{760}$, collected north of Chakdehia, where it is clearly interbedded with the slates. The

points of difference are its texture which is finer-grained, and its structure which is more ophitic. The degree of alteration of the minerals is perhaps less, but the mode of alteration is exactly the same. The original structure is very well preserved. Even the original twinning of the augites is reproduced in the uralite.

Such is again $\frac{11}{757}$ which was found about half way between Girwi and Naogai, but not *in situ;* it was a spheroidal boulder. It is greyish green in colour, with a mottled appearance in the hand-specimen. The specific gravity is 2·91. It contains the same minerals as $\frac{11}{773}$ with the addition of a large proportion of calcite. The original structure is difficult to make out exactly owing to the changes that have taken place: it seems that the original augites had crystallised largely before the felspars. They are now entirely changed to uralite, and in a few cases the frayed edges of the crystals show a slight bending which indicate that the structure may be partly due to subsequent movement in the rock mass. At the same time we have undoubted proof of the secondary growth of the hornblende. Where the uralite comes in contact with some of the large patches of the easily yielding mineral chlorite, it has grown into those spaces, assuming the shape and the characteristic sharp angles of the amphibole prism. The original limits of the crystal may sometimes be recognised owing to their green colour, the additional growth consisting of colourless actinolite.

In the midst of the chlorite patches there occur also pale hornblende crystals which are perfectly idiomorphic. It is probable that these do not represent any paramorphic change of augite originally situated at the place which these crystals occupy, but they are entirely new formations derived from material furnished possibly by minerals of various species. Calcite and chlorite form large patches through the uralites. The calcite often forms idiomorphic crystals through the chlorite aggregates. The felspars are somewhat clouded owing to kaolinisation, the effect of atmospheric weathering. They are otherwise almost unaltered. Leucoxene occurs in the same manner as in the rocks already described, sometimes with a small unaltered nucleus of ilmenite.

d.—Finer-grained lavas, altered basalt (melaphyre).

There is every gradation from these diabases to the finer-grained altered basalts or melaphyres. The greatly altered rock $\frac{11}{761}$ mentioned above on page 81 is already fine-grained enough to deserve that appellation. No other rock observed in the Son region exhibits such a degree of alteration, but some of the rocks from the Jabalpur outcrop of the Bijawars are very similar, for instance, $\frac{21}{106}$, $\frac{21}{102}$ and $\frac{21}{71}$. $\frac{21}{106}$ is somewhat schistose and coarser-grained than $\frac{11}{761}$. The felspar seldom shows any traces of its original crystal outlines. The hornblende is fibrous, bent and curved giving wavy extinction. There are patches of chlorite associated with well-shaped epidote crystals. The chlorite does not form a felted scaly aggregate, but is in crystallographic continuity over the whole area of the patches. It may have grown in the place of some pre-existing porphyritic constituent as we shall find to be the case in another melaphyre from Dholki in the Son region. There are numerous patches of leucoxene.

Melaphyres.

Similar rocks from Jabalpur.

$\frac{21}{102}$ shows nothing but a very fine-grained felted aggregate of fibrous hornblende and minutely granular felspar. Almost all the hornblende fibres are more or less curved. There are secondary quartz and calcite, and little or no trace remains of the original structure. $\frac{21}{71}$ is still finer-grained. The hand-specimen is greyish-green. It consists of green hornblende in minute fibres, felspar, leucoxene, chlorite and epidote. The structure is not entirely obliterated and the felspar microliths can still be discerned.

Returning now to the Son region, there is a very similar rock from Deora, $\frac{2}{1054}$, collected by Mr. Bose. It belongs to the more northern of two great volcanic outcrops represented on figure 5. It is a schistose scoriaceous melaphyre. The hand-specimen is of green colour and is speckled with small rounded masses of chlorite. It also shows elongated masses of calcite with a flattened elliptical section. These

Son region.

represent drawn-out cavities subsequently infilled by the mineral, so that the rock may have been originally a scoriaceous basalt. As to the small chlorite masses, if they were also filled up cavities, we would expect to see them assume the same shape as the larger ones filled with calcite, instead of which their dimensions are only very slightly greater along the direction of bedding. They are perhaps pseudomorphs after some porphyritic constituents whose crystals were arranged along the direction of flow. Under the microscope the fine groundmass of the rock is quite similar to that described in the case of the Jabalpur rock $\frac{21}{71}$. It consists of hornblende, felspar, leucoxene and chlorite. The hornblende is in minute prisms and fibres frequently curved. The felspars give wavy extinction, and their mass is penetrated into by chlorite and minute hornblende needles that entirely obscure their crystalline outline. Leucoxene occurs in large quantity forming streaks and patches all over the section. The chlorite masses appear under the microscope as spherical or ovoid aggregate of felted chlorite scales associated with epidote and calcite. The secondary growth of the minerals surrounding these patches has generally obscured the shape of the original porphyritic mineral whose place they occupy. In a few cases the shape may still be partly recognised, and it would seem that the original mineral was olivine. The rock would then be very similar to the one next to be examined.

Altered olivine-basalt.

This is a very fine-grained melaphyre with porphyritic augite and olivine, collected at Jarkarua in the river bed immediately north of the Red Shale boundary (specimen $\frac{11}{764}$). The point 3 (Fig. 6) is in the direct continuation of its strike. It occurs therefore at a short distance from the band containing the diabase $\frac{11}{769}$ which we found to contain unaltered augite (page 82), and this remarkable feature is again exhibited in the melaphyre $\frac{11}{764}$, showing that this must be a region of lesser metamorphism amongst the Bijawars. It resembles a basalt in the hand-specimen with, however, a greenish tinge, and is mottled all over with dark green

Unaltered augite.

silky patches of chlorite which are found to be pseudomorphs after olivine. The specific gravity is 3·03. The microscopic section shows idiomorphic porphyritic crystals of augite and of the altered olivine scattered through a minutely fine-grained matrix exhibiting typical basaltic structure. The augites, like those of the rock $\frac{11}{769}$, belong to the pale-coloured variety and they also appear very transparent in the hand-specimen. Some of them seem to have been corroded by the magma. Again as in $\frac{11}{769}$ the augite of the groundmass is altered to minute hornblende needles. The felspar is, however, quite unaltered, and the shape of the minute microlites which it constitutes, very well preserved. The base also contains chlorite and epidote. Ilmenite is scattered throughout the base in minute grains as is seen in many typical basalts and it is only partly altered to leucoxene. The groundmass of the rock is very similar to that of $\frac{11}{778}$ from Girwi, described on page 80, only without the larger porphyritic felspars. The most interesting feature is, however, the olivine, porphyritic crystals of which constituted originally a large proportion of the rock. It is entirely altered to chlorite, but the outlines of the crystals are admirably preserved. A feature worthy of notice is that the optic axis of the chlorite coincides with one of the crystallographic axes of the original olivines and the pseudomorphs give perfectly straight extinction. Sometimes the totality of the chlorite is developed parallel to one axis of the olivine, or else a smaller proportion coincides with another axis at right angles to the first one, in which case a series of meshes is produced which probably represents the original cracks in the olivine. This alteration might be compared to the change of enstatite into bastite. Detached flakes of the chlorite give the characteristic uniaxial figure of that mineral in convergent polarised light. The mineral exhibits a bright pleochroism from green to pale yellow, and the pseudomorphs form remarkably beautiful objects under the microscope.

Curious pseudomorphs of chlorite after olivine.

e.—Tuffs, etc.

In most localities where there is any great development of volcanic strata, the true igneous lavas are accompanied by great thicknesses of sedimentary tuffs, consisting of volcanic fragments redistributed by water. These tuffs often surpass in importance the lavas themselves. In a region like the one under examination, where the lavas themselves are considerably altered, it is to be expected that changes at least as great would take place amongst these much looser materials. The great thicknesses of chlorite schists which have already been alluded to as accompanying these lavas may be looked upon as the altered representatives of these tuffs. The secondary mineral chlorite represents the altered ferro-magnesian silicates, and owing to the great development of this mineral, the rocks in this closely folded district have become completely schistose, and all trace of the original structure has disappeared. These rocks usually contain calcite in such a large proportion as to deserve the name of chlorite limestone or chlorite cipollino. The calcite may be largely derived from the alteration of the original minerals, but it results partly from simultaneous deposition, for the schists contain lenticular masses of limestone interleaved between their foliæ, and massive limestone beds are frequently intercalated. (See above, page 69.) As already mentioned the calcite itself may be volcanic in origin, the limestones being of the nature of travertine.

Tuffs.

Chlorite schists.

These chlorite schists often contain both pyrites and magnetite. The pyrites crystals are sometimes of fairly large size and they occur in the form of cubes with striated faces, as is very common with that mineral. They are sometimes largely altered to hematite without, however, the slightest change in their crystalline shape. The smaller crystals are complete pseudomorphs, while the larger ones have an outer shell of hematite that sends irregular branching extensions into the inner mass of the crystal, much of which still consists of pyrites.

Pyrites altered to hematite.

Rocks of doubtful nature.

In addition to these schists which we may safely regard as altered tuffs, the strata of the volcanic bands are occasionally associated with various rocks of puzzling appearance, and for which I can offer yet no definite suggestion as to their nature or mode of origin.

Quartz-epidote rock.

Such is $\frac{11}{747}$ which consists almost entirely of epidote and quartz. The quartz is continuous over large areas. Both minerals are much obscured by a white opaque substance which is very finely divided. It occurs S. E. of Maoghun associated with the volcanic rocks; but the exposure is not clear enough to make out its relation to them.

Quartz-calcite rock.

$\frac{11}{763}$ however is clearly interbedded. It occurs immediately north of the most northerly run of Agori jaspers, on the road from Khattai to Maoghun. In the hand-specimen it has the appearance of an impure limestone, green in colour, mottled blue with more coarsely crystalline patches. Under the microscope it appears to consist almost entirely of an intimate mixture of quartz and calcite (or dolomite). Skeleton and fern-like forms of an opaque white or yellow substance are abundantly scattered. Some portions of the section are bounded by such regular lines that they have quite the appearance of pseudomorphs. These portions are richer in the carbonates, and the opaque microlites are absent from it. The rock gives the impression of being entirely pseudomorphous.

$\frac{11}{782}$ collected east of Jungel is very similar, but with a more confuse and brecciated appearance. In addition to the minerals contained in $\frac{11}{763}$, there is chlorite, serpentine, chalcedony and magnetite, the latter mineral having also a pseudomorphous appearance.

f.—Conclusion.

We may conclude by saying that it is well established that an extensive series of basic volcanic rocks occur amongst the Bijawars, particularly in the Son region. These volcanic rocks consist of both lavas and tuffs.

Unaltered examples of the lavas have been found in Bundelkhand, and represent doleritic and basaltic types of varying degrees of coarseness, consisting principally of labradorite, augite and ilmenite or magnetite, with varying quantities of olivine. They are remarkable, moreover, for the frequent presence of micrographic quartz.

Owing to the great compression which the Bijawars have suffered in the Son region, the rocks there are much metamorphosed. The augite is almost always altered to uralite, and it seems also to have combined with some of the substance of the felspars giving rise to a less ferriferous hornblende. These changes are accompanied by the formation of chlorite, calcite, and epidote. The felspar is usually saussuritised, its chemical alteration being generally inversely proportional to the amount of fracturing which it has suffered. Fresh olivine is never met with, and one rock shows an interesting transformation of that mineral into regularly oriented chlorite. Ilmenite is universally changed into leucoxene. Pyrites is usually largely developed.

Far more abundant than the lavas are the tuffs in which transformations of an exactly similar nature have taken place. The great preponderance of chlorite gives them generally a schistose structure. They contain calcite in large proportion and are interbedded with great limestone masses whose true nature is perhaps that of travertine.

It has been sometimes stated that basic volcanic rocks are rare or absent amongst the older sediments. This impression may have resulted from the fact that owing to their great liability to considerable metamorphism, the older basic lavas have not been recognised as such and have remained unnoticed. The data at present available are probably insufficient to estimate whether the proportion between acid and basic volcanic rocks throughout the world has varied in successive geological periods, but the existence of considerable quantities of basic lavas in many pre-cambrian systems is well established.

In the present case, we find no well-defined law in the succession

of rocks, for the next volcanic outbreak at the time of the lower Vindhyans was of acid lavas, and later again we have the basic flows of the later Deccan-trap period. It is true that there elapsed such a long period between the formation of each of these three volcanic systems, that there may be no connection between them.

CHAPTER V.—THE VOLCANIC ROCKS OF THE LOWER VINDHYAN SERIES. (E. VREDENBURG.)

"Porcellanites" and "trappoids".

Various opinions have been expressed concerning the real nature of the porcellanic and "trappoid" beds that constitute a considerable proportion of the lower Vindhyans. Some analyses published by Mr. Mallet (Memoirs, Geological Survey of India, Vol. VII, page 128) show them to be very similar in their composition to igneous rocks, the coarser-grained varieties or "trappoids" especially so. Yet, owing to their undoubtedly sedimentary character and the absence of any foci of volcanic activity, the conclusion was arrived at that they are results of purely aqueous sedimentation and derived from the disintegration of felspathic gneisses and granites, the coarser rocks being of the nature of felspathic sandstone, or arkose, the porcellanites on the other hand representing indurated beds of finer-divided material. Yet even in the Memoir quoted above, some doubt is expressed as to this being the true explanation. "It is perhaps doubtful whether the highly igneous looking rock of Hoorkahoorkee may not have a different origin" (page 128). The glass-like clearness of the felspars in many of the specimens is difficult to reconcile with the idea that it was derived from a granitic or gneissose rock.

Previous opinions.

At the time of the earlier descriptions of these rocks, the microscope had not yet been applied to their study. The examination of a number of microscopical sections has resulted in showing that the rocks are tuffs. In any accumulation of volcanic rocks, whether acid or basic, the tuffs are often found to surpass the real lavas in bulk. With acid lavas it is an almost constant rule, for the eruptions are principally explosive in character, and the imperfectly fluid lavas seldom flow to any great distance.

Rocks are of the nature of the tuffs.

As a typical specimen of the coarser rocks or "trappoids" we may take the rocks $\frac{10}{707}$ and $\frac{10}{708}$ collected by Mr. Oldham at Baheria and

Kua. The appearance in the hand-specimen is not altogether unlike that of an arkose, though the grains are seen to be separated from one another by the porcellanic looking matrix analogous to that constituting the "porcellanites." This matrix has become so indurated that the fractured surfaces run indifferently across it, and the embedded crystals, as though they were one homogeneous substance. But a glance at the microscopic section shows that the rock cannot have resulted from the usual process of igneous sedimentation. The grains constituting it are so different in size that they could not represent particles resulting from ordinary weathering re-distributed by flowing water. Their shape militates also against that explanation, for they are generally quite angular. Some of them are idiomorphic crystals, while others have their outlines rounded, not in the somewhat rough manner of ordinary sand-grains, but with a very smooth outline and re-entering contours which indicate that the crystals have been corroded by a molten magma. Lastly, these grains of varying size are imbedded in a matrix so fine-grained that its detailed structure becomes visible only under the microscope.

Not only are the structures of the rock different from those resulting from purely aqueous sedimentation, but the minerals are of quite a different nature from those constituting the neighbouring gneiss. The latter are perfectly allotriomorphic and always exhibit unmistakable signs of granulation and dynamo-metamorphism. The two specimens of "trappoids" alluded to consist principally of felspar and quartz, the felspar being largely in excess, which would agree with the analyses given in the Memoirs. So far from resembling the minerals of the gneiss, all the particles constituting these rocks are unmistakably volcanic in origin. Both the felspar and quartz are corroded in the manner so characteristic of rhyolites. Orthoclase and oligoclase are both present. Some of the orthoclase is locally altered to microcline, but this might result from the strains that must have been produced during the folding of the lower Vindhyans. The quartz

Minerals of volcanic origin.

extinguishes uniformly, or with a very slight waviness which may be attributed to the same reason. It is full of glass inclusions. Besides the grains of quartz and felspar, there are a great many fragments similar to them in size and irregularity of outline, and consisting either of micro-crystalline rhyolite, or of a glass with imbedded felspar microliths, or even of obsidian which remains without any action on polarised light.

The fine groundmass consists principally of small grains of felspar and quartz and fragments of devitrified glass through which are scattered flakes of biotite. Occasionally grains of calcite are met with.

Most of the other specimens examined microscopically ($\frac{10}{590}$, $\frac{11}{863}$, and $\frac{11}{864}$) are essentially similar in all their characters. The two specimens $\frac{11}{863}$ and $\frac{11}{864}$ are from a much lower horizon than the "porcellanic stage," as they were both gathered from bands occurring interbedded with the shales of the division No. 1 of Mr. Mallet's nomenclature. Porcellanites also are found similarly situated. $\frac{11}{863}$ is from the region of Kon Khas, $\frac{11}{864}$ from the Garbandh outlier.

Secondary growth of quartz.

The lower Vindhyan sandstones are frequently, though by no means invariably, transformed into highly compact quartzites owing to a secondary growth of the quartz-grains, so that the rounded grains which were originally more or less independent, have been united into a compact aggregate of intergrown crystals. This tendency is particularly manifest whenever the rocks contain any volcanic material even in small proportion, as if the silica contained in the colloid glass were particularly liable to solution and re-deposition. To this kind of action, more perhaps than to devitrification, is due the extremely homogeneous aspect and compact nature of the porcellanites. It has just been mentioned in speaking of the trappoids that amongst the angular fragments which they contain, a great many consist of micro-crystalline rhyolite. It is of course very difficult to say whether this micro-crystalline structure is original or the result of subsequent devitrification. There is, in favour of its being partly original, the fact that perfectly allotropic fragments of obsidian are

found side by side with them; and that some rhyolite fragments contain idiomorphic felspars with subsequent enlargement of the *felspar* which could only have taken place when the mass was partly molten, and which shows that the crystalline nature of the groundmass is an original feature at least in the immediate neighbourhood of the porphyritic crystals. But there is no doubt as to the large extent to which secondary crystallisation of quartz has taken place, so that angular fragments of micro-crystalline rhyolite, whose shapes are perfectly definite in ordinary light, appear with quite confused boundaries in polarised light, and can scarcely be distinguished from the surrounding aggregate of minute grains. These angular fragments apparently quite similar to the matrix containing them may be observed even in hand-specimens of the porcellanites. This is easily understood on the supposition that the rocks are the result of showers of volcanic dust in which the fragments lack the uniformity in size obtained in a purely sedimentary rock deposited from water flowing with a definite speed, and the extent to which secondary crystallisation has gone on gives great similarity to both the matrix and the included fragments. In fact under the microscope, the "porcellanites" appear quite similar to the matrix of the "trappoids." The two rocks are practically identical, the only difference being that the porcellanites do not contain the larger fragments characteristic of the "trappoids." The perfectly homogeneous appearance and compact nature of the rock is due, as above stated, to secondary crystallisation of quartz, but in a thin section the component particles when not actually visible with the naked eye, may be discerned at once by the aid of a pocket lens. The sections are resolved by the lowest powers of the microscope, the boundaries of the crystalline components being particularly clear in polarised light. The size of these particles varies between extremely wide limits, just as in the case of the trappoids, and without any regular arrangement of grains of one particular size in definite layers. The minerals are exactly the same as in the case

Porcellanites.

of the "trappoids." The *débris* are all exceedingly angular and irregular, and owing to their fragmentary condition, the grains cannot always be identified as quartz or felspar; but as a considerable proportion can be recognised for certain as felspar, it is most probable that here again, as in the case of the trappoids, felspar is in greater abundance than quartz.

In these porcellanites, just as in the trappoids, the felspar is usually perfectly clear. On the supposition that the rocks were an aqueo-sedimentary one, the felspar must have travelled over great distances to be comminuted into such small fragments; it would be very surprising then that it should remain unaltered, showing no trace of the atmospheric alteration to which it is so liable. Fine-grained sediments do not, as a rule, contain felspar: they may consist largely of such minerals as quartz or mica, or iron ores, but the felspar is represented entirely by its atmospheric decomposition products, principally kaolin. Unaltered felspar is usually found only in sediments of the coarseness of sandstone; and even then, except in the case of an arkose produced in immediate proximity to a granite, it is quite subordinate to quartz in quantity.

Characters of felspar.

In addition to felspar and quartz, the porcellanites consist to a large extent of fragments of more or less devitrified glass, and grains of micro-crystalline rhyolite which often contain small idiomorphic apatites. Grains of calcite and small crystals of hornblende are also met with. Fragments of pumice are abundant, often of comparatively large size.

Apatite, hornblende, etc.

Observations on a larger series of specimens than I have been able to examine would no doubt bring out many interesting points. Still the evidence is sufficient to show that these rocks are certainly not derived from the disintegration of gneiss, which had been hitherto the most generally accepted theory.

At the same time, microscopic examination shows that the rocks are not purely igneous: that is, they are not of the nature of lavas. Their mode of occurrence in the field also leads to the same

conclusion, for they resemble ordinary sediments in their forming narrow beds of rapidly alternating composition, remaining constant horizontally over wide exposures, the structure being further emphasized by the very regular bands of different colours that frequently give the porcellanites their characteristically striped appearance.

It seems quite clear therefore that these rocks are volcanic tuffs. There remains but one difficulty to be dealt with, it is the apparent absence of any volcanic centres from which this large bulk of materials could have been derived.

Position of volcanic centres.

The only sign of the former site of a volcano that one could expect to discover would be in the shape of an intrusion. So far as the Vindhyans themselves are concerned, the chances of finding any dykes traversing them are small, for the eruptions took place in the earlier stages of this formation. The rocks belonging to this stage outcrop along a very narrow belt of country, owing to the peculiar structure of the Vindhyans whose southernmost and therefore lowermost beds are usually vertical or nearly so. It would require therefore a combination of specially favourable circumstances, in order that a dyke traversing rocks of that age should be exhibited amongst these beds. If the volcanic centres originally existed north of the line of country occupied at present by the outcrop of the lowermost stages of the Vindhyans, they are of course entirely concealed by subsequent formations. The only chance of finding an igneous dyke of that series is therefore south of the Vindhyan outcrop, on the supposition that there ever occurred any in that situation.

About the meridian of the Rer (or Rehand) the belt of land occupied by the Bijawar and Archæan, bounded to the north by the Vindhyans, and to the south by the Gondwanas, has a considerable width, as much as fifty miles. No acid dykes have been recorded as running through these formations; yet their examination cannot be said to have been so thorough as to preclude all possibility of any such having been overlooked. In a westerly direction the space between the

Vindhyans and the Gondwanas becomes rapidly narrower, so that the chances of discovering these dykes become proportionally less. Eastwards, the Archæan and all the other rocks become greatly concealed by alluvium and have not been studied in detail. My own work did not extend so far east as the Koel river. But in the Survey collection there exist specimens of "trappoids" from the district east of that river, and these proved on microscopical examination to be true igneous rocks.

Exposures near Kutumbeh.

The exposures from which these specimens have been derived occur south-east of Rotasgurh, or more exactly south of Kutumbeh (Lat. 24° 37', Long. 84° 17"). Here the trappoids are described as resting immediately upon the gneiss, and consequently the lowermost divisions of the series are stated in previous publications to be missing: "In the outliers, however, which occur in the alluvium south-east of Rotasgurh, the conglomerate is entirely absent, as well as the next two members of the series, and beds, apparently representing the trappoid band No. 4, rest directly on the crystalline rocks" (Memoirs, Vol. VII, page 32; the same statement is again made on page 36). I may just mention that this observation does not necessarily entail the disappearance of the stages 1, 2 and 3 by an overlap of No. 4. The band No. 4 corresponds to the period of maximum deposition of the "trappoids," but it has been ascertained they occur at intervals, both above and below that horizon, and are often fairly abundant towards the base of the series. Moreover, as will be shown hereafter, these Kutumbeh rocks are most probably of the nature of intrusive sills, and would be newer, therefore, than the horizon to which they appear to belong.

Rocks described by Mr. Medlicott.

This is how Mr. Medlicott describes one of these occurrences in his Progress Report of 1863-64: "I will now notice this felspathic Son rock in its extreme form. Last season (63-64), in working along the crystalline boundary from the east, I was awfully puzzled when I came to the Kalapahars—a very conspicuous and remarkable group of dome hills South of Kootoombeh, These complete domes are formed of the most

amorphous variety of the coarse, porphyritic pseudo-granite; great bare masses presenting acres of convex surface without a crack. Closely packed between these domes and encircling their bases is a pseudo-crystalline rock—a rock which in a hand-specimen I would have set down as a granitoid trap, or trappoid granite; compact felspar being largely present. I got one observation showing more fully the relation of this rock to the thorough-looking granite. On the path leading from the village of Kala-pahar on the North, through the hills to Kota on the South, the first low dome on the right hand presents an exceptional feature: over a large portion of the boss, and reaching quite to the top, there is the remains of an outer shell, of a most regular thickness, some six or seven feet. This upper crust is of the trappoid variety, and it is in sharp contact with the coarsely crystalline central mass, just like two strata; on the East side the edge of the outer mass is straight, giving the appearance as if half the dome were entirely composed of it; but on the West side the edge is not continuous with that on the East, and is, moreover, broken and indented, leaving no doubt that the coarse rock underlies throughout."

After describing some more similar occurrences, Mr. Medlicott comes to the following conclusion: "These sections leave little doubt as to the origin of these peculiar Sone strata, though much remains to be observed and considered as to the conditions of their formation. I can hardly seriously entertain the view of their being trappean or volcanic."

The same opinion is given in the Memoirs (Vol. VII, page 36). "It rests directly on granitoid gneiss, and its examination strongly leads one to believe in its being a sedimentary rock made up of the *débris* of the latter." The results of subsequent examination have now caused these conclusions to be modified to a certain extent.

Both the gneiss (specimen $\frac{11}{72}$) and the overlying "trappoid" (specimens $\frac{1}{159}$ and $\frac{1}{169}$) are represented in the collection. The gneiss $\frac{11}{72}$ is described in the register as "granitic gneiss on which the trappoid rock rests with perfectly sharp junction." In the hand-specimen it appears as

Gneiss of Kalapahar.

a coarse granite with no trace of foliation, this being probably apparent only in the field. Strain phenomena are, however, manifest in the microscopic section. The rock has the composition of an ordinary biotite-granite. It consists of quartz, orthoclase, oligoclase, biotite and sphene. All the minerals are perfectly allotriomorphic, The quartz shows not only strain shadows, but even the initial stages of mosaic formation. The orthoclase shows microclinic structure. The felspars are largely altered to saussurite and epidote.

The minerals of such a rock are sufficiently characteristic to be recognised in a fragmentary condition in a microscopic section of the overlying rock, if it were true that this is an arkose made up of their *débris*. Far from its being sedimentary, however, it appears in the microscopic sections of both the specimens $\frac{19}{15}$ and $\frac{1}{169}$, as a rock so thoroughly crystalline, that it can only be regarded as an intrusive rock, for it is doubtful whether rhyolitic lavas can ever be so completely holocrystalline.

Microgranites.

In the hand-specimen the rock is whitish-grey with a greenish tinge, and the crowded porphyritic crystals give it a granitoid appearance. One of the specimens, $\frac{1}{169}$, when examined microscopically, appears most remarkably crystalline. The large porphyritic constituents, usually quite idiomorphic, are plagioclase felspar in crystals that are admirably zoned when seen in polarised light, and biotite in hexagonal prisms. These lie in a groundmass of plagioclase, orthoclase, and quartz, all of which are locally idiomorphic, while elsewhere the structure is micrographic. Lastly, the remaining interstices between the grains of this growth of smaller crystals are occupied by micropegmatite. The felspars are sometimes altered with formation of epidote, otherwise they are perfectly clear and transparent.

The rock is therefore totally unlike the under-lying gneiss, while all its constituent minerals are identical with those observed in the "trappoids," with this difference that the structure is thoroughly igneous instead of being partly clastic. The only mineral not seen in this section, although so common in the "trappoids," is the porphyritic

quartz ; but the next rock from the same exposure $\frac{1}{159}$ shows it in abundance. In this rock the porphyritic constituents are plagioclase, orthoclase, quartz, and biotite. The quartz is corroded to such an extent by the magma that all crystal outline is obliterated. The felspars are quite idiomorphic, although they have been also slightly corroded, particularly the orthoclases. The plagioclase shows beautiful zoning, while the orthoclase exhibits obscurely the initial stage of the microcline condition. As in $\frac{1}{169}$ the felspars are partly altered with production of epidote, and this mineral, together with chlorite, has also resulted from the alteration of the biotites. The once molten magma is entirely crystallised, the structure being spherulitic, or rather pseudo-spherulitic, for the spherulites consist of quartz and felspar. In many rhyolites, although this composite structure of the spherulites is very probable, yet it cannot be ascertained beyond doubt on account of the minute dimension of their fibres. In the present case it is indicated by the great irregularity of the dark cross which they exhibit in polarised light ; and it is definitely established by examining them with the highest power of the microscope, for it is then observed that the structure is an exceedingly minute micrographic one ; so minute as to be just upon the limits of visibility, yet perfectly distinct.

The groundmass of $\frac{1}{159}$ is therefore comparable to that of $\frac{1}{169}$ being only on a very much more minute scale, and it is probable that a detailed study of the Kalapahar outcrop would bring to light a complete series of gradations.

Rocks near Jupla, collected by Mr. Medlicott.

Similar rocks exist in the neighbourhood of Jupla (Lat. 24° 32′, Long. 84° 4′). This is how Mr. Medlicott describes the occurrence : " A more extensive patch of the same rock occurs at the very edge of the crystalline area South-East of Jupla, and in the little detached hill of Aliuneggur. Here several varieties of granitoid and gneissose rock are clearly overlaid by different forms of the derivative stratified rocks, both compact and pseudo-crystalline." The collection contains a specimen of this rock (No. $\frac{1}{159}$) labelled " trappoid rock resting on the dome-gneiss of

Aliuneggur, just as at Kalapahar." Here again microscopic examination shows it to be not a derivative rock, but an igneous rock similar to those already described. Under the microscope it resembles best the more perfectly crystalline rock $\frac{1}{169}$. It consists of porphyritic and idiomorphic plagioclases, biotites, and hornblendes, in a micrograniticand micrographic groundmass of quartz and felspar very similar to that of $\frac{1}{169}$ only on a much smaller scale; it is therefore somewhat intermediate in character between $\frac{1}{169}$ and $\frac{1}{159}$. Although the two rocks $\frac{1}{169}$ and $\frac{1}{168}$ do not possess any large porphyritic crystals of quartz like in the case of $\frac{1}{169}$, yet that mineral is present in such abundance in the base that it probably exists in the same proportion in all three specimens. Considering that the two more highly crystalline varieties must have taken longer to solidify, it might be suggested that the absence of porphyritic quartz is due to its complete solution by the magma, for the crystals are already corroded to a great extent in the less perfectly crystalline rock $\frac{1}{168}$ whose magma must have solidified more rapidly.

The accounts given of the manner in which all these rocks occur certainly give the impression that though they are not true beds of lava, they are probably intrusive sheets. In any case they are vastly newer than the more intense phase of foliation of the region, for these signs of dynamic-metamorphism so conspicuous in the granitic gneiss are absent from the overlying felsites, or only very weakly exhibited, and belong to the same order of disturbance as that generally seen in the Vindhyans. The complete similarity of their minerals with those of the Vindhyan tuffs makes it very probable that they are genetically related, and we have here, in fact, one of the volcanic foci from which these rocks were derived in such abundance.

Rocks collected by Mr. Medlicott at Nabinagar.

Finally there is one more exposure where the connection of these rocks with the ordinary stratified porcellanites is beyond doubt. It is in this same neighbourhood, at Nabinagar (Lat. 24° 36′, Long. 84° 11′). Mr. Medlicott describes it in the following terms : " My next

day's work brought me to the little hills close to Nubbeenuggur. I expected to find quartzite such as protrudes from the alluvium to the East and which shows again at Jupla to the West. It proved, however, to be a massive rock closely akin if not identical with the trappoid variety of Kalapahar, and intimately associated with sharply bedded Sone rocks of the felspathic type; the coarse trappoid rock shows massively in two small bosses near the end of the low ridge on the South; the sharply bedded rocks of the ridge have a low undulating dip to North-North-West; among them are thicker beds of coarser variety and showing evident affinities to the massive rock, which I suspect only the outcrop of a very thick bed." It is possible that the thick bed to the south is a real lava-flow, while those interbedded with the porcellanites might be tuffs. But the connection between the two is beyond doubt. Originally the rocks were represented in the collection by two specimens, $\frac{1}{155}$ described as "coarse variety of trappoid from Nubbeenuggur," and $\frac{1}{156}$ labelled "ditto"; is seen well interstratified with finely-bedded rocks, S. of Kokha. Presumably $\frac{1}{155}$ is the rock from the more massive exposure. It is unfortunate that the specimen $\frac{1}{156}$ has been lost, as it would have been otherwise interesting to compare the two, but $\frac{1}{155}$ is a typical lava. It has in the hand-specimen the appearance of a coarsely porphyritic rhyolite. The matrix is partly pale-coloured and resembling that of the ordinary "trappoids," while elsewhere irregular veins or branches of black obsidian run through it, containing large porphyritic felspars as much as one centimetre in diameter and porphyritic quartz.

Under the microscope the rock is seen to consist of idiomorphic or fragmentary crystals of quartz, orthoclase, and plagioclase, showing the usual phenomena of corrosion, principally in the case of the quartz. The groundmass is crypto-crystalline and shows conspicuous flow-structure. Both the crystals and groundmass are identical in character with the fragments constituting the "trappoids" and "porcellanites."

Volcanic focus.

We may now safely conclude that the region between Kutumbeh and Japla is in the neighbourhood of one of the principal foci of activity of the Vindhyan period.

Whether or not similar foci are so situated with respect to denudation of the overlying strata that they may come to be discovered on further investigation, yet the identification of one igneous centre of acid volcanic rocks of lower Vindhyan age is sufficient to remove the only difficulty which, in the absence of any such recognised feature, did still subsist in realising the true nature of the Vindhyan tuffs.

Composite types.

As a consequence of this identification, the gradations which have been observed between the "trappoids" and "porcellanites" on the one hand, and on the other hand such rocks as limestones, shales, or sandstones, receive an easy explanation, for as the deposition of these tuffs did not necessarily interrupt the purely aqueous sedimentation which was simultaneously progressing, it follows that when the proportion of volcanic material became smaller, intermediate types of rocks were formed. Moreover, some of the eruptions may have taken place partly on land, and denudation would at once act upon the lavas and loose scoriæ whose fragments would be mingled with the quartz-grains of sandstones, or, according to their size, with the smaller fragments constituting finer sediments.

Porcellanites not quite so typical in character as those forming the bulk of the "porcellanic stage" are frequently met with in the division No. 1 of the lower Vindhyans. The reason for this may be that the porcellanic stage represents the period of maximum activity during which an enormous quantity of igneous fragments was allowed to accumulate so quickly as to form sediments consisting entirely or nearly so of volcanic materials. On the other hand, during the more scattered eruptions of the earlier Vindhyan stages the amount of ejectamenta may not have been so considerable as to generally give rise to beds formed exclusively of such materials. This would account for the more shaly appearance of so many of these earlier types.

Rocks from the Garbandh outlier.

The rock $\frac{11}{854}$ which resembles both the porcellanites and trappoids contains a large admixture of non-volcanic material. It occurs amongst the complex

strata of the Garbandh outlier, belonging to the division No. 1 of the lower Vindhyans, and containing a large proportion of "trappoids" and "porcellanites." In the hand-specimen it has an irregular aspect resembling the porcellanites at one place, while in other portions the admixture of included fragments gives it the appearance of the "trappoids," while lastly some parts are so quartzitic as to resemble a tuffaceous sandstone, all these changes taking place in the space of a few inches. Under the microscope the tuffaceous nature of the rock seems evident from the extreme irregularity in size and frequent angularity of the fragments. The presence of numerous fragments of a rhyolitic groundmass shows moreover that generally the component fragments are to a large extent volcanic. At the same time, there are other fragments undoubtedly derived from the gneiss, such as pieces of granulated mosaic quartz and fragments of tourmaline. This rock therefore may be regarded as a passage type between tuffaceous and true aqueous sediments. Secondary deposition of quartz, which is the cause of the compact nature of the porcellanites and trappoids, is rendered extremely conspicuous in this rock and in the one next to be described owing to secondary growth of the larger quartz-grains.

$\frac{11}{855}$ which occurs a short distance from the rock just described, is a light-grey compact sandstone, so felspathic that under the influence of weathering it becomes covered with a decomposition crust very similar to that which forms upon the "trappoids." It also possesses the sub-conchoidal fracture of these rocks. It consists of quartz, orthoclase, and rhyolite fragments, but the microscopic structure is quite different from that presented by the "trappoids." It is a true sandstone of regular structure in which all the grains are of sensibly the same dimension. They are all well rounded and the quartz is largely in excess of the grains of felspar and rhyolite. It is probable that a large portion of the quartz and perhaps all the felspar may be volcanic in origin, but the fragments have been completely redistributed by a process of true sedimentation. The compact nature of the rock is due to considerable secondary silicification. The grains of quartz

Secondary silicification.

all present secondary enlargement, by means of which their rounded outline is completely lost in polarised light when the rock appears to be composed of closely interlocking polyhedral grains. This secondary growth even extends through many of the original grains of rhyolite, which, in polarised light, appear as cloudy patches through a continuous area of quartz. Many of these grains may have been originally vitreous, and, as already suggested, it is probaby from them that the silica has been largely dissolved and recrystallised. The same action taking place right through the minute particles of the "porcellanites" and of the groundmass of the "trappoids" would account for their extreme compactness and their conchoidal fracture.

Jasper, chert.

In addition to these volcanic strata, the division No. 1 contains also porcellanoid rocks which are of a totally different nature and consist of chert or jasper. Such are the siliceous bands and segregations that frequently occur in the limestones (specimen $\frac{11}{871}$) and allied rocks occasionally interstratified with the shales (specimens $\frac{11}{860}$ and $\frac{11}{861}$). Even here the silica may have been deposited by thermal waters connected with the volcanic centres, but the structure is not that of a fragmentary tuff. However much the rocks may resemble "porcellanites" in the hand-specimen, the sections show nothing but a perfectly regular fine-grained mass of quartz or chalcedony.

Conclusion.

In conclusion it may be said that the "trappoids" and "porcellanites" that form a large proportion of the lower Vindhyan strata and whose true nature has remained for a long time an undecided question, are rhyolitic tuffs of varying coarseness. In one locality, between Japla and Kutumbeh, felsites and true lavas have been found, which indicate the proximity of a centre of eruption. These lavas occur at the base of the series and in other regions tuffs occur at all stages of the division No. 1, generally resembling those that form the bulk of the "porcellanic" stage. Porcellanic beds of a few feet in thickness also occur here and there above the main porcellanic horizon, throughout the Kheinjua

stage. It may be concluded from this distribution that an extensive series of acid eruptions began simultaneously with, or just before the commencement of, the Vindhyan era. At the time of maximum activity, showers of fine volcanic dust together with coarser *débris* were ejected in enormous quantity giving rise to the tuffs forming the "porcellanic stage". The beds occasionally found at higher horizons may represent stray eruptions belonging to a period of declining activity. The eruptions were confined to the region occupied by the Son outcrop and adjoining districts, for it appears that the "trappoid beds" do not reappear in Bundelkhand (Mem., Vol. VII, page 45). By far the greatest majority of the specimens indicate subaqueous conditions. It is not inconceivable that acid lava-flows emerging from subaqueous volcanic vents would, on coming in contact with the oceanic water, become superficially so rapidly cooled as to reduce them to a fragmentary condition by irregular, violent and sudden contraction of the molten glass. In this way, the true tuffs—that is those ejected in a fragmentary state by explosive action—would be augmented considerably by such disintegration of the materials which actually appeared at the volcanic outlet in the form of ordinary acid lava. This suggestion possibly accounts for the fact that the fragmentary materials in these beds so greatly exceed the true lavas in quantity, and in fact are the predominating variety of the volcanic products. The rearrangement of silica in the rocks which has given them their porcellanic character, is a feature which might well be expected to be accentuated in volcanic rocks of subaqueous origin. Such conditions of formation are naturally favourable to the rapid chemical action of water on the unstable volcanic glass.

CHAPTER VI.—COUNTRY BETWEEN THE SON AND THE BANAS. (R. D. OLDHAM.)

The area lying within the bend of the Son, where it turns from a northerly to an easterly course, after receiving the Mahanadi, is occupied principally by lower Vindhyan rocks. These are thrown into an anticlinal fold to the north, and a synclinal to the south, the two areas being separated by a fault.

Section in the Son.

The bed of the Son, from the junction of the Mahanadi to where it turns southwards towards Marai, is occupied by a band of limestone which shows up very conspicuously at the junction and at intervals on the banks down stream. Southwards from this, along the Son, a series of shales and sandstones are seen underlying the limestone just referred to. They strike at first to N.-N.-W. and afterwards to S.-S.-E. and the lime-stone band seen at the junction of the Mahanadi is seen once more. It can be traced for only a short distance east of the Son, being cut out by the fault which brings up the beds of the porcellanite stage.

The fault is marked in the Son by a very sudden change of dip, the 30° dip to S.-S-.E. of the limestone giving way to a vertical dip in the beds of the porcellanite stage. This vertical dip soon bends over to horizontal and then to S.-S.-E. again, the beds forming an open synclinal in whose centre the limestone of the Mahanadi forms a broad exposure. The porcellanite stage re-appears south of Ramgarh and beyond them come the basal sandstone, which, when seen on the bank of the Son, are thin, fine-grained, and difficult to distinguish from some of the quartzites of the transitions.

Lower Vindhyan east of the Son.

To the east of the Son the two outcrops of the porcellanite stage are joined in the manner shown in the map. In this area the rocks of this stage are full of fragments of felspar and quartz, giving them a very porphyritic appearance, but they are still well bedded and interstratified with shales. In the bed of the Son one bed of the northern outcrop,

which is specially porphyritic, forms a small waterfall, and on the broken edge of the bed it is seen to have an obscure columnar jointing.

The basement beds, traced to the east from the Son, thicken considerably and soon form a conspicuous ridge, which is interrupted by an oblique fault about a mile east of the Son, and the gap so formed has been utilised by a small tributary of the Son. Eastwards of this gap the sandstones thicken and the ridge increases in height till it runs into the hills west of Tikhua; here it forms the northern flank of the hills and is apparently cut off by a fault. It is by no means certain that the rocks of this horizon are not represented in the southern and south-western portion of the area which has been included in the Kharara outlier of the upper Vindhyans.

Conglomerates are rare in this outcrop of the basement beds. Some pebbly bands are seen at the base of the section in the stream which flows down from Panrui, and in that which flows past Margarh, where there is a thickness of fully 1,000 feet exposed.

To the north of the basement sandstones there is only a narrow band of shales near the Son, but in the plain east of Margarh the exposure broadens out very greatly. The area occupied indicates a great thickening and the few exposures seen have all tolerably high dips, indicating a good deal of disturbance, but there is no indication of the existence of any rock belonging to one of the higher stages.

North of the line of fault there is a broad open anticlinal of beds belonging to the lower part of the Kheinjua stage, whose axis runs from one to two miles south of the Son. The rocks exposed consist of shales and sandstones, the latter frequently ripple-marked and, where tolerably pure, indurated into quartzites.

Neighbourhood of Marai.

The neighbourhood of Marai proved more difficult to map than any other part of the area surveyed, and its interpretation still remains doubtful as regards some points. To the north-east of Marai the basement beds of the

lower Vindhyans form a very conspicuous ridge running away to north-eastwards. This ridge terminates on the bank of the Son near Bukailli in a sharply folded anticlinal whose axis dips to the south-west; the sandstones are again bent up by a synclinal and the ridge continues, with a steady decreasing importance consequent on a decreasing thickness of the hard beds, till it is crossed by the stream which flows past Marai. Beyond this the sandstone can be traced with difficulty through low jungle-covered hills where it forms no defined surface feature, and is altered almost beyond recognition by weathering. It appears to bend round, much as shown in the map, and end up against the great fault which had been traced from the Son.

Above basement sandstones come fine-grained greenish shales overlaid by a thick band of limestone, at the base of the porcellanite stage. These horizons can be traced with ease on the Son river near Narwar, and in the bed of the Son at that village the limestone and porcellanites are seen bending round from a north-westerly to a southerly dip, the outcrops of the hard bands forming a series of curved barriers across the river bed. To the south of this Son no exposure of the porcellanite stage could be found, but in the bed of the stream flowing west of Ghusra, the limestone is exposed. The country here is deeply covered by river deposits and no exposures are seen, but the most probable explanation is that the outcrop of these hard beds is cut off by a fault.

Red shale series.

The fault which had been traced from the Son forms the northern boundary of an outcrop of the red shale series whose western extremity runs under the scarps of the Kharara outlier, from below which the beds issue with a nearly vertical dip. The northern boundary of this outcrop is a natural one, the basement beds being represented by a thin sandstone. The northern boundary is formed by the fault referred to for about five miles; beyond this the northern boundary is a natural one, the basement beds being seen, where not hidden by surface deposits, to the neighbourhood of the Samdin.

Transitions.

The transitions near Marai are profusely veined with gneissose granite throughout the low ground, these grow more abundant towards the granite outcrop of the Sitkuri plain, the boundary between the transitions and crystallines being very indefinite. In the hills west of Shahargar no intrusions were found, a fact which suggests that the existence of these hills is due to the greater resistance of the rocks of which they are composed, as compared with those of the low ground which have been penetrated by veins of the felspathic readily decomposable granite.

Further to the east, near the Samdin and north of the red shale outcrop, the transitions are represented by green hornblendic schists, and some bands of jaspideous quartzites.

South of the outcrop of the red shale series the transitions are free from granitic intrusion. There are banded quartzites of the Bijawar type between which and the scarp of the Kharara hill are phyllites and slaty beds, some of which are red in colour.

Doubtful exposure near Shahargar.

Within the transition area a conspicuous scarped hill is rising over, and to the east of the village of Shahargar is capped by a hard conglomeratic quartzite. It is an isolated exposure in a very much disturbed region, and there is nothing to show which of the horizons, at which similar rocks are found, it belongs to.

The Kharara outlier of upper Vindhyans.

The Kharara outlier of upper Vindhyan rocks forms an elevated range of hills, more or less plateau-like on its summit, which has a length of about 12 miles and a breadth of from 1 to 4 miles, bounded for the greater part by prominent scarps. It derives its name from the village of Kharara situated about the centre of the broadest part of the outlier, but not as it happens, on the upper Vindhyan outcrop. This village has given its name to the Kharara station of the Great Trigonometrical Survey, situated on the highest peak of the range, on a hill which is locally known as Dubhiabar.

The Dubhiabar hill is composed of nearly horizontally bedded sandstones, resting on highly inclined schistose slates, the bottom

beds being a dull red sandstone full of fragments of the underlying rock. Above these come red coloured conglomeratic sandstones, capped by red sandstone without pebbles.

South of Kharara village the pebbly sandstones overlie the transition rocks with a south-easterly dip of 30° to 35°, and about a mile and a quarter beyond are cut off by a fault which, for some 84 miles, forms the boundary of the upper Vindhyans. Where this boundary traverses the high ground north-east of Pansrer (Pansra) it is well marked by the vegetation. The Vindhyan rocks bear the usual scattered vegetation and thorny trees of the well drained hill tops, while the transitions, better adapted to retain moisture, are covered with a thick ground of *Sál* trees which extend right to the boundary and rise along it in many cases as abruptly as if they were an artificial plantation.

South of Barhata the scarp of the outlier is composed of a white quartzitic sandstone, containing small fragments of white quartz and felspar, the latter generally decomposed. Similar beds are seen to north and west of the village, but in the latter direction they are overlaid by red sandstone with jasper pebbles.

Section north of Barhata.

North of this village is a very instructive section. To the south-east of Kunmou the white quartzitic basement beds of the lower Vindhyans form a range of hills, behind which comes broken ground occupied by the red shales, and these again give way apparently by a fault to phyllites of the transitions. Crossing these we come to a coarse conglomerate, containing many ill-rounded fragments of red jasper and numerous white quartz pebbles of 6 inches and more in diameter, besides darker coloured and less conspicuous fragments of quartzite, the whole being cemented by a matrix of dark red sandstone. These conglomerates, which have a maximum thickness of about 250 to 300 feet, form a prominent peak on the western water-shed of the stream which flows northwards from Barhata. They are overlaid by an accumulation of angular fragments of slate and phyllite, of the same character as the transition rocks of the immediate

neighbourhood. This breccia consists of a mass of angular fragments of slate, often almost or quite free from finer-grained matrix, and so closely packed that, where the surface is covered with vegetation, the imperfect exposures might easily be taken for transition slates. Through this breccia, which is principally composed of small fragments of a few inches across, are scattered blocks of white vein quartz, running to a foot in diameter and only rounded to a small extent on the angles.

Ascending the section which is shown in Fig. 7 the breccia becomes more and more mixed with sand and finally passes into the hard, white, quartzitic sandstones of the Barhata plateau, by which it is overlaid. The thickness of the beds between the coarse conglomerate and the white sandstone is about 700 feet on this section.

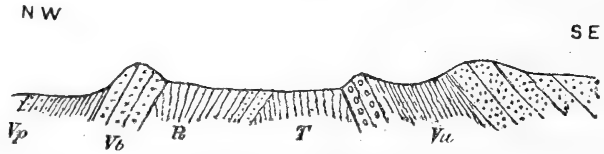


Fig. 7. Section north-west of Barhata. *T*, transition; *R*, red shale series; *Vb*, basal stage; *Vp*, porcellanite stage of lower Vindhyans; *Vu*, upper Vindhyans. Scale 2 in. = 1 mile.

Traced in either direction the coarse-grained beds rapidly thin out, and more rapidly to the south-west than to the north-east. The coarse conglomerate does not extend for more than quarter of a mile, the breccia thins out and disappears at about three-quarters of a mile to the north-east and half a mile to the south-west of the section in the valley, and beyond this the white sandstones are in direct contact with the older rocks. A section drawn along the strike, and at right angles to that shown in Fig. 7, would consequently be something like Fig. 8.

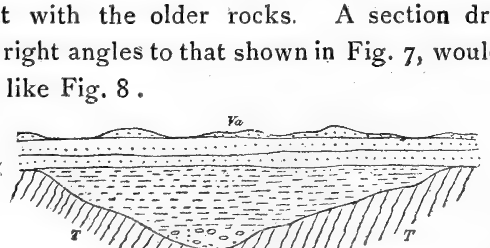


Fig. 8. Section at right angles to Fig. 7. Scale and lettering as before.

An old land surface.

The history of deposition indicated by this section shows an old land surface traversed by a valley of 700 feet in depth, on whose bottom a stream of torrential nature formed a deposit of coarse conglomerate. Then by a change of level or of the volume of the stream the conditions of deposition changed and the valley became filled by a fan of local *débris*, which in its turn gave way to, and was covered by, a widespread deposit of sand under which the original irregularities of the surface were covered up.

A short way further east of this section conglomerates are largely developed in the section along the stream which flows down from the Kharara village and descends to a low level. It is possible that there may be another old valley here, but the fan deposits are wanting, and it was not possible to determine whether the descent of the boundary was not due to disturbance.

Eastern end of outlier.

The eastern termination of the outlier is composed almost entirely of white sandstone, frequently containing numerous small fragments of white vein quartz, and usually more or less felspathic, or at times containing distinct grains of felspar. West of Sejari, the lowest beds seen in the scarp contain numerous boulders as large as a man's head, many being of bright-vermilion coloured jasper. The rock is very like some of the basement beds of the lower Vindhyans as seen about five miles to the north-west. There can be no question of the identity of the two, however, for it is just at this point that the rocks of the Kharara outlier are found resting in absolute unconformity on the eroded edges of upturned strata of lower Vindhyan age (see Fig. 9).

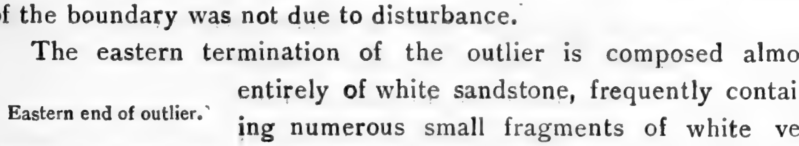


Fig. 9. Section through east end of the Kharara outlier. *T*, transition; *R*, red shale series; *Vb*, basal stage; *Vp*, porcellanite stage; *Vu*, upper Vindhyan.

To the north-west of the Barhatola the white quartzitic sandstones again contain a rock very similar to one that is found among the basement beds of the lower Vindhyans in the exposure to the north. It is a very peculiar rock, composed of white quartz reticulated through a ferruginous-argillaceous matrix, which weathers into a vesicular quartz rock by the disappearance of the other constituent.

Smaller outliers.

A group of small outliers in the comparatively low ground near Bholahra may be conveniently noticed here. They are of small size and being exposed at a low level where there is not the free drainage, which the main exposure has on account of its greater elevation, they are not surrounded by scarps, but form low hills covered with a deep layer of loose gravel.

One more outlier may be mentioned here, which caps the hills east of the Samdin and north of Sejari. It contains some coarse conglomerate, and at its western extremity I found the only boulder of crystalline gneiss which I have seen in these beds.

Transitions of the Samdin valley.

In the Kharara valley and to the south of Pansrer the transitions consist of phyllites and quartzites with numerous small outcrops of an intrusive diorite, of which some larger exposures are seen near the villages of Bhanni-Bhowraha (Bhaoraha), and east of Garu. To the north of these intrusions is a band of volcanic rocks, extending to the northern boundary of the transitions. Ashes and amygdaloidal lavas are easily recognizable in spite of the alteration they have undergone, by which most of the beds have been transformed into a more or less hornblendic green-coloured schistose rock, while other beds have been largely converted into epidote.

North of Deori is a range of scarped, craggy hills, especially conspicuous when seen from the north, which run north-eastwards from the neighbourhood of Ghara. On the north they are in contact with felspathic quartzites which have decomposed to a soft kaolin rock, and to the south are decomposed quartzose beds, some white,

others bright red. In the centre of these soft rocks is the band of hard massive quartzites which forms the line of crags.

A similar quartzite, associated with similar rocks, is seen west of Tikhua, and is very probably of the same age.

Upper Gondwana.

The upper Gondwanas south of the transition area do not require special notice. Their boundary runs for some distance in a straight line before suffering a change of direction. It is clearly a fault, but observations made further east, and off the map, show that this fault was in all probability contemporaneous with, or anterior to, the deposition of the upper Gondwana shales and sandstones. The present boundary is, consequently, in the main one of original deposition and not due to removal of the upheaved portion of a once more extensive deposit.

Outliers south of the main boundary.

In one place, east of Tikhua, the boundary overlaps this fault line for a short distance, and the beds north of the line differ in character from those to the south. Instead of being clays and sandstones free from pebbles, we have conglomerates containing numerous pebbles, some of red jasper and others of a conglomerate containing red jasper fragments, which have evidently been derived from the upper Vindhyan beds seen to the north.

South of Bhanni is a small outlier of upper Gondwanas, exposed in a stream-bed, and near Pipreri village soft, weathered white clay spotted with reddish patches is exposed in a swampy hollow which may not improbably be an outlier of upper Gondwana rocks. In neither case were the boundaries traceable.

Lower Vindhyan outlier.

At the eastern end of the Kharara plateau, lower Vindhyan beds appear from under the scarp. In the bed of the Samdin the basement bed has a vertical dip and is composed of a breccia of fragments of banded ferruginous quartzites exactly similar to the rock with which it is in immediate contact. This breccia is overlaid by a sandstone with pebbles, the thickness of the two being not more than 20 feet. Above the sandstone come about 200 feet of fine-grained

shales and above them the porcellanite stage. As seen in the bed of the Samdin these rocks were not immediately recognised, being softer than usual with a larger proportion of green-coloured beds and an intermixture of red shales. A short way to the east, however, these rocks pass into the normal type of the stage.

The porcellanites are overlaid by shales and sandstones, the highest beds seen being purple sandstone, slightly calcareous with ophitic calcite crystals of about one-eighth inch and occasionally one-quarter inch diameter, whose cleavage faces show as glistening patches on the fractured surface of the rock.

The northern limit of the lower Vindhyans is a fault which brings in transition schists, followed immediately by the basement bed of the red shale series overlaid by the beds of this series, forming the continuation of the outcrop which has been traced from the neighbourhood of Marai. Where the bottom quartzite of this series crosses the Samdin it takes a sudden bend to the north, the quartzite having a northerly strike in the stream-bed. The line of outcrop on the east of the Samdin is some 300 yards to the north of the outcrop on the west, and the same displacement has occurred in the fault bounding the lower Vindhyans.

Red shale series.

The northern boundary of the red shales is a fault, beyond which the transition quartzites and phyllites continue to the boundary of the great expanse of crystalline gneiss and granite in the Son.

East of the Samdin the termination of the Marai exposure of the red shale series takes the form of a number of isolated patches of the basal conglomerate, sometimes associated with the overlying red shales. These patches form low elongated ridges striking about north-east by east, the dip being to the north-west. The structure here is very complicated and could not be worked out in detail on the somewhat imperfect map available. On the quarter-inch map attached to this report the delineation has necessarily been purely diagrammatical.

The chief features of the disturbance of this tract appear to be a series of strike faults running about north-east by east with upthrow to the north-west, crossed by other faults running about east and west, whose upthrow is indifferently on the north or south. This band of faulting probably extends into the transition area, where it cannot be traced owing to want of contrast in the rocks. Over a limited area it is detected owing to the fact that fragments of the red shale series have been preserved, resting with a dip of 45° to 60° to north-west by north on an eroded surface of transition schists.

Lower Vindhyan.

The southern limit of this zone of complicated faulting is the great fault, with downthrow to the north, forming the northern boundary of the lower Vindhyan outlier whose exposure in the Samdin valley has just been described.

East of the Samdin the uppermost beds of this outlier can be traced for about 3½ miles, when the outlier narrows to a width of about half a mile and the highest beds seen belong to the porcellanite stage. The basal conglomerate can be traced continuously along the southern margin of this outlier to the Banas. West of the Samdin, under the scarp of the upper Vindhyans, it consists of dirty, impure sandstones with scattered pebbles, overlaid by red sandstone and sandy shale. In the gorge of the Samdin its exposure has already been described. Traced eastwards it forms an inconspicuous rise crossing the low ground in a north-easterly direction till it comes into contact with the basal conglomerate of the red shale series, the two combining to form a conspicuous ridge on the northern slope of which a contact section was seen showing the lower Vindhyan basal conglomerate resting unconformably on the sandstone of the basal beds of the red shale series.

Further north-east the lower Vindhyans are in contact with the red shales, and north of Nakni the conglomerate, which forms a conspicuous ridge, is very coarse, containing boulders a foot and more in diameter. Hence it is traceable to the Banas, but nowhere so coarse-grained as north of Nakni.

Red shale series.

The red shale series, which is not seen in the Samdin, comes in a short distance to the east, the exposure broadening out rapidly, attaining a width of nearly 1½ mile near Nakni. The bottom conglomerate is cut out in places by faults running nearly east and west, but east of the Nakni stream it is continuous, attaining a considerable thickness and forming high prominent hills about a couple of miles west of the Banas.

The beds above the bottom conglomerate are of the normal type of red and green shales. Near the Banas the uppermost beds seen are greenish and schistose beds containing numerous grains of sand scattered through the argillaceous matrix.

Crystalline rock.

The crystalline rocks immediately south of the main exposure of the lower Vindhyans are very badly exposed. Owing to the readiness with which they decompose they have formed an area of low ground surrounded by the hills of the transitions on the south and the ridge of lower Vindhyan basal conglomerate on the north. This low ground is deeply covered with an accumulation of dust deposits and no exposures are seen except in the stream-beds.

East of Chachai the junction of the granite and transition schists is seen in the bed of the Samdin, the gneissose granite forming strings and tongues penetrating the schists. Along the junction lines in some parts fragments of schist are included in the granite, and the foliation of the schists is better developed in the immediate neighbourhood of the contact. At other parts the contact is abrupt and clean-cut, these being due to displacements to which the rock has been subjected after the intrusion and solidification of the granite.

In the bed of the Son the granite is freely exposed, and it is seen that the basic dykes which penetrate it cannot be traced continuously for any distance, being cut off and displaced by dislocations of the rock

CHAPTER VII.—COUNTRY BETWEEN THE BANAS AND LONG. 82° 00′ E.

(R. D. OLDHAM.)

Lower Vindhyan main area.

In the main area of the lower Vindhyans the bottom beds cross the Son just below the junction of the Banas with the Son and extend eastwards for about 20 miles forming a bold range of hills, to which the name Kheinjua is attached on some of the old maps. The eastern termination of this range is cut off by an oblique fault running west by north; the outcrop is thrown about three miles northwards by this and another nearly parallel fault and then runs continuously to Long. 82°. Coincident with the faulting the thickness of the bottom sandstones lessens and north of the plain of Sidi it no longer forms a continuous ridge.

The beds above the bottom quartzite attain their maximum extent near Samaria and Karowndia, this being principally due to repetition of outcrops by faulting and folding, but also to a greater development of the beds themselves.

West of Samaria there is a small outlier of the crystallines surrounded, except for a short distance on the east where the boundary is faulted, by the bottom conglomerate of the lower Vindhyans, which is seen in some sections to be immediately overlaid by limestone. The bottom beds all round this inlier have much less thickness than in the main exposure to the south, and at the eastern end are so much reduced that the outcrops can only be traced with difficulty. Near Pori there is an exposure of a hard, grey, crystalline and somewhat siliceous limestone, veined with quartz, which weathers into a ferruginous quartz-breccia; the occurrence of some quartzites of an older look than those of the lower Vindhyans at the eastern end of the inlier, and the fact that the exposure of the limestone just referred to lies inside the run of the boundary, suggests that it is transition, and that a small area of rocks of this age is exposed at the eastern end of the inlier.

The porcellanite stage and the overlying beds south of the Son present no specially noteworthy peculiarities between the Banas and Long. 82°.

Lower Vindhyan outlier.

To the east of the Banas the outlier of lower Vindhyans and underlying red shale series can be traced for a distance of 26 miles, the outcrops of the two combined being never so much as a mile in width. Throughout the whole of this length the southern boundary is a natural one and the northern a fault with upthrow to the north, and as an outcrop of this form indicates, the beds are everywhere vertical or nearly so, and very much sheared.

The porcellanites of the lower Vindhyans are seen in the Banas but die out against the boundary fault at between two and three miles to the east. The bottom quartzite and shales associated with it can be traced to a little beyond Mata, forming a tolerably continuous ridge for the whole distance.

Red shale series.

The area occupied by the red shale series forms an open valley, bounded on one side by the ridge of lower Vindhyan bottom quartzite and on the other by a series of hills having a more or less E.N.E. strike, composed partly of the transitions and partly of the bottom conglomerate of the red shale series. This last appears to vary very much in thickness, partly due to original variation of deposition, partly to subsequent disturbance. The bedding is always at high angles and the pebbles have been drawn out in the direction of dip, fractured and indented by the pressure of adjacent pebbles. As a result of these variations in thickness the conglomerate does not form a continuous ridge but a discontinuous line of hills, the coatings between them being covered up by recent deposits.

About Sendhwa the beds above the bottom conglomerate consist of a green schistose rock, full of grains of quartz, which would not have been recognised as belonging to this series but for the continuity of outcrop.

At the eastern extremity of the outcrop of the red shale series

the boundary fault divides and the outcrop tails off in two tongues both bounded on the north by faults.

Upper Vindhyans: Pabia outlier.

Immediately north of the eastern termination of the outcrop of the red shale series comes the second of the exposures of sandstone which have been regarded as upper Vindhyan. The rock is of the same type as in the Kharara plateau and the exposure is limited on three sides by denudation only, the sandstones resting in unconformable contact on the transition schists or on the syenitic rocks intrusive in them. The southern boundary is a fault with a downthrow to the north.

In the case of this outlier, and the smaller one close to the west of it, there is no direct proof of the age. About four miles to east-north-east there is a hill covered with a broad expanse and a considerable thickness of an exactly similar rock, which can there be shown to belong to the red shale series. In the case of the Pabia exposure it is, however, difficult to ascribe the sandstones to this age. Not only is the great difference in thickness between the sandstones of the Pabia hill and of the outlier of the red shale series immediately to the south against such a supposition, but the difference in degree of disturbance points to a difference in age. Besides the difference in degree of disturbance, there is the fact that the northern boundary of the narrow, intensely disturbed, outlier is a fault with an upthrow to the north, while the southern boundary of the broad area of moderately disturbed sandstones is a nearly parallel fault half a mile distant and with an upthrow to the south. It is probable that the Pabia sandstones originally extended further to the south and that the fault by which they are cut off was of later origin than the one which bounds the outcrops of the red shale series.[1]

Transition and Crystalline rocks.

The mapping of the transitions and crystallines in this region is almost exclusively due to Lala Kishen Sing. The boundaries are of the same type as is found

[1] In his progress report on this area Mr. H. B. Medlicott wrote: "I found large *débris* of trap on the top of Pabia, for which my observations of rock *in situ* do not afford an explanation." I can confirm this in so far as the discovery of a single fragment of a dioritic rock and the absence of intrusions goes. The fragments seen by Mr. Medlicott and myself were probably carried up from the low ground, very possibly by men of the stone age, who appear to have found the tough hornblendic rocks of the transitions useful as hammer stones.

elsewhere, and there do not appear to be any special features to be noted.

Gondwanas.

The Gondwana boundary takes a bend southwards, a short way east of the Banas, and at the same time becomes an ordinary boundary of unconformable contact. Near Sureyha the boundary once more assumes a faulted form which it maintains nearly to the Gopat. Thence for some three or four miles its nature becomes doubtful once more, but before the 82° meridian is reached, it again assumes the faulted form.

About three miles west of Marhwas the upper Gondwanas cease and the rocks in contact with the crystallines belong to the Damudar series, till near the Gopat an outlier of the upper Gondwanas is again found in contact with the crystallines.

CHAPTER VIII.—COUNTRY NORTH OF THE SON BETWEEN LONG. 82° AND 82° 30′ E.

(R. D. OLDHAM.)

Lower Vindhyan main area.

In the main area of lower Vindhyans the lower stages of the series are exposed with a somewhat complicated structure, being thrown into numerous folds and cut by many faults. There are two inliers of gneiss in this area.

The basement beds in the country north of Khaira were found by Mr. Grimes to be penetrated by quartz-veins which pass downwards into the granite. These veins must, however, be of later date than the majority of the quartz-veins which are found in the crystalline area and are in many places truncated by the surface of unconformable contact at the base of the lower Vindhyans.

In this same area a conglomeratic band is found at the base of the porcellanite stage, the pebbles consisting of a green fine-grained rock, undistinguishable from similar beds which are found interstratified in this stage. The great expanse of rocks of this stage to the south of Sahaol is partly accounted for by repetition through folding; there can, however, be little doubt that north of latitude 24° 30′ Mr. Datta has included a greater thickness of strata in this stage than was done by Mr. Grimes and myself in the country to the south. There are very few exposures in the northern part of the area coloured as porcellanite, and the northern boundary is based on two isolated exposures in the Son, which may either be inliers of the rocks included, to the south, in the porcellanite stage, or more probably stray beds of a similar rock in the Kheinjuas.

At the eastern end of the area, along the 83° meridian, these beds have thinned out and at the same time become much less characteristic.

About Bardi the rocks of the Kheinjua stage occupy a considerable area, and it may be well to correct a statement reproduced in Mr. Mallet's memoir[1] that the limestone No. 7 as well as the beds above and below are missing at Bardi. There is certainly a limestone at Bardi, which might well be Mr. Mallet's No. 7, if there were any constancy in a particular group of beds in this series, and there is a considerable section of shales and sandstones intervening between the shales with calcareous concretions and the beds of the porcellanite stage which is given as follows by Mr. Datta[2]:—

Section N. by W.—S. by E. by Bardi.

(Descending order.)

(*a*) Argillaceous shales, dark grey to blackish, containing calcareous concretions, passing down into a thin band of finely laminated light grey to whitish shale with crystals of quartz. Well seen on the left bank of the Son, north-west of Bardi.

(*b*) Blank.

(*c*) Thin-bedded sandstone (with an occasional thick bed), with subordinate bands of shales. These are the beds on which Bardi itself stands and are well exposed on the right bank of the Gopat here.

(*d*) Limestone with shales: composed of an upper band of grey, yellowish to pinkish limestone, thick bedded and cherty, succeeded by greenish argillaceous shales, and these being underlaid by a thinner band of rather impure limestone with intercalations of arenaceous layers. Well exposed on the right bank of the Son at 2½ miles W. by N. of Bardi; seen also on the Gopat just south-west of Bardi itself.

(*e*) Shales, greenish (argillaceous as well as arenaceous), with thin-bedded sandstone.

(*f*) Blank.

Porcellanites.

Upper Vindhyan outlier.

North of the outlier of lower Vindhyans comes the third of the outliers of upper Vindhyans, that of the Dadri plateau. The age of the sandstones comprising this outlier is not so definitely proved as in the case of the Kharara outlier, for they nowhere rest in unconformable contact on

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 38.

[2] Rec., Geol. Surv. Ind., Vol. XXIX., p. 80.

lower Vindhyan rocks. The two, however, are exposed in close proximity to each other in circumstances which preclude the idea of their being of the same age.

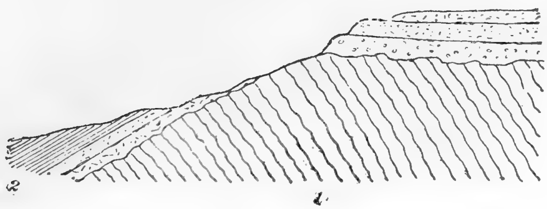


Fig. 10. Section on south face of Dadri hill, west of Tarka.
1, Transition; *2*, lower Vindhyan; *3*, upper Vindhyan.

About a mile to a mile and a half west of Tarka the bottom conglomerate of the lower Vindhyans is exposed with a dip to the southwards of about 20°, resting on transition quartzites of Bijawar type, which dip northwards at 60°, or at nearly a right angle to the lower Vindhyans. The contact rock is an angular breccia of talus *débris*. On the spurs the exposure of lower Vindhyans runs up the slope, and on some of the spurs the narrow gap between them and the edge of the sandstone of the plateau is so thickly covered with *débris* of the latter that it would not be difficult to regard the two as continuous with each other. On other spurs, however, the gap between the two is comparatively clear of *débris* and the bottom bed of the lower Vindhyans is exposed within 300 yards of the sandstones of the plateau, the two contrasting in character most markedly.

The lower Vindhyan basement beds consist of an angular breccia overlaid by pebbly sandstone, and this again by impure sandstones without pebbles. The rocks of the plateau have no basal breccia such as the contact rock of the lower Vindhyans. There is a much greater thickness of coarse-grained beds and the rock itself is whiter and cleaner, has a softer and more grating surface, and contains a larger number of pebbles, though of smaller size, than the neighbouring sandstone of lower Vindhyan age. The contrast is too great to allow of the two being of the same age, and the comparatively moderate

disturbance of the sandstones of the plateau is against their being ascribed to the red shale series.

The mode of occurrence, induration and general appearance of these beds is so near those of the Kharara sandstones of the Kharara hill, that there would, on this ground alone, be good reason for attributing them to the same age. The rock is more uniformly a sandstone; the lowest bed often contains many large imperfectly rounded pebbles of quartzite, but above this and over most of the surface of the hill the prevailing rock is a moderately fine-grained felspathic sandstone, somewhat micaceous, mostly white or nearly so, though not infrequently tinged with red and at times passing into a dull red sandstone.

West-south-west of Dadri village there is a peculiarity in the boundary which is interesting as an indication of the nature and extent of the denudation which preceded the deposition of the sandstones. North of Pokhra there is a long straight ridge of dark coloured Bijawar quartzite. This ridge is interrupted by a cross valley west of Jholukhor, but continues on the other side of the valley as a spur of the Dadri plateau. The sandstone is not, however, continuous across the top of this spur, which rises as a low ridge from the sandstones on either side, and runs east by north to within half a mile of Dadri.

At the eastern end of this ridge there is a little faulting, the surface of the sandstones to the north lying about 30 feet below that of the same sandstones to the south, and this fault continues to be marked by a slight scarp even beyond the termination of the transition outcrop. This fault is quite insufficient to account for the exposure of the Bijawar quartzites, and their presence is only explicable on the supposition that the older rocks had not only undergone practically all their present disturbance when the sandstones were deposited, but had also been exposed to extensive denudation of a nature which left the hard bands standing out as elevated ridges.

Red shale series.

About three miles north-east of the Pabia hill another outcrop of the red shale series begins. The bottom beds occupy a considerable area and on the

Batrani hill their thickness has caused them to form a very conspicuous exposure of a rock very similar to that of the Pabia hill.

The red shales series lies in a synclinal, complicated by minor foldings, and after about six miles from the western extremity of the exposure are unconformably overlaid by the lower Vindhyans, which occupy the hollow of the same synclinal, but completely overstep the red shales on the north and rest in direct contact on the transition schists and quartzites.

Lower Vindhyan outlier.

On the south the lower Vindhyans are in natural contact with the red shale series, a narrow strip of which is cut off on the south by a fault which, for a short distance, cuts them out altogether and brings the lower Vindhyans into direct contact with the transitions.

The basement beds of the lower Vindhyans only attain a small development in this outlier, but the form is noteworthy. Along the northern boundary the lowest bed is usually a breccia of angular fragments of the immediately contiguous transition rocks, a formation which only differs from the talus accumulations now being formed by its induration. In the neighbourhood of Tarka this is overlaid by a rock with a very fine-grained siliceous matrix, through which are scattered angular fragments of transition quartzites ; it is, in fact, an indurated form of a deposit which is common enough along the foot of hills, especially in a somewhat dry climate.

Towards the Gopat and for about three miles to the east the northern boundary of the outlier is faulted, but beyond that once more becomes natural to the termination of the outcrop about two miles east of Harphari. The southern boundary is not seen where it crosses the Gopat, but south of Dol, where the basement bed of the lower Vindhyans re-appears from under the recent deposits, the boundary is one of unconformable contact with the red shale series. In the Mohan the basement beds are exposed twice over, being repeated by an oblique fault, and thence extend eastwards in contact with the red shale series till, at their terminations, the two outcrops run free of each other.

The thickness of beds exposed below the long narrow outcrop of beds of the porcellanic stage is much broader on the south than on the north, a difference which is in part due to a higher dip, and, near the Gopat, to the northern boundary being faulted. Further west where the northern boundary is one of original contact, the exposures on the southern half of the syncline are much more imperfect than on the north, but it is difficult to resist the impression that a greater thickness of beds are exposed.

The basement beds of conglomerate and sandstone are for the most part thin and do not form conspicuous topographical features, but in the eastern part of the outlier there is a thick band of strong quartzite near the upper part of the shales below the porcellanite stage, which forms a conspicuous ridge. Among these shales are some limestone bands, one of which is seen at the crossing of the Mohan between Dol and Rehi.

The porcellanites present no feature of note. They are the highest beds exposed and form a band of very broken ground, the low hills being traversed by numerous cross valleys, many still occupied by streams, while others are now dry owing to the streams they originally carried having been cut off by valleys cut back along the strike of the soft shales on either side.

Another small outlier of lower Vindhyans is found south of the Mohan. It is separated on the north from the larger outlier by an anticlinal along whose axis the red shales are exposed. Only the coarse-grained basement beds are seen, which are more developed than in the principal outlier. They form a synclinal whose eastern end forms the hollow in which the plain of Khamaria lies, while to the west the axis rises and the conglomerates are found along the crest of a ridge which rises south of the east-and-west reach of the Gopat. The southern boundary of this outlier is marked by a fault, along which the transition beds are brought up into contact with the lower Vindhyans, except for a small patch of red shales, too small to mark on the map, which is found between the lower Vindhyan conglomerate and the transitions, to the south of Ragwar.

This fault has almost died out by the time it reaches the Mohan, and for a couple of miles to the west of that river the bottom conglomerates of the red shale series are found, in original contact with the transitions, to the south of the line of fault. In and east of the Mohan the red shale outcrop attains a width of nearly three miles. The shales are largely developed and might almost be called slates as they are hard enough to form rounded pebbles, which are extremely abundant in all the stream-beds within the area of the red shale outcrop.

Red shale series.

Among these shales Mr. Vredenburg found veins of barytes, from an inch to over a foot in thickness, near the village of Bharra.

Barytes.

East of the Mohan the sandstone beds of this series thicken considerably and form bold scarps overlooking the low ground round Ghurder. Further east the termination of the outcrop takes the form of a narrow rib of quartzite and conglomerate, dipping northwards against a fault. For the last four miles of its course, before the outcrop tails out, it has run clear of the lower Vindhyans.

Among the transitions of the area under consideration there are several runs of conglomerate, of which three principal ones require special notice.

Transitions.

The first of these forms the ridge running about E. N. E.-W. S. W., immediately north of the stream called Jhiria [1] on the map; that which flows north of the Dadri outlier. It consists here of a quartzite through which numerous pebbles of an older quartzite are scattered. The transition volcanics are seen in the ground to the south, but the relationship of this conglomerate to them has not been made out. A similar rock, probably of the same age, is found in contact with the lower Vindhyans in the stream-bed and on the hill sides near Saru. No pebbles of red jasper were seen in this exposure.

[1] Jhiria in the local vernacular is a generic name for a stream and is applied to innumerable streams throughout the district examined: few of these streams have any distinctive name, but are called after the villages they flow through.

Newer conglomerates.

A more extensive run of conglomerates, probably of later date, is found south of the lower Vindhyan outliers. Mr. Vredenburg has traced it continuously from the neighbourhood of Madhopurwa to the Mohan river, which it crosses immediately south of the boundary of the red shale series. Thence it continues close to the southern boundary of the lower Vindhyans to the Gopat. West of the Gopat the outcrop trends away from the red shale boundary, and is very well seen in the stream which flows down from Danri to the Gopat. Beyond this the outcrop was not traced but was seen at intervals to about south of Sendura, and is doubtless continuous or nearly so for the whole of this distance.

The conglomerates of this horizon are coarse and contain numerous fragments of the red jasper of the Bijawar type. The conglomerates pass upwards, in a northern direction, into soft slaty or even shaly beds of grey and purple colour among which some bands of sandstone and grit are found. Some of the beds are not unlike those of the red shale series where these are most indurated, but there is a marked unconformity between the two series.

South of and running up approximately parallel to the conglomerate outcrop just described is another conglomerate of very different and peculiar type. It consists of a fine-grained argillaceous matrix, now slaty or schistose, through which are scattered rounded pebbles and boulders, some of great size. The rock is in fact an indurated boulder clay, of a structure similar to the glacial boulder clays of Europe and the Talchir boulder bed. Apart from this structure, however, there are no other indications of glacial origin and the simile employed must not be taken as intended to do more than indicate the constitution of the bed.

This boulder-bearing bed has been traced from the neighbourhood of Bannai to the Gopat. The rocks between it and the other conglomerate are more schistose than those to the north of the latter, and no fragments of red jasper have been found in the boulder slate. Taking these facts into consideration it is at least

probable that the boulder slate is older than the true conglomerate which runs to the north of, and nearly parallel with it.

Crystallines.

The crystalline area between Longitudes 82° and 82° 30′ seems chiefly remarkable, so far as a very cursory examination shows, for the development of a very porphyritic gneissose granite, in which the longer axes of the crystals of orthoclase point in every direction, showing no tendency to parallelism either with each other or with the very obscure foliation.

Gondwanas.

The Gondwana rocks in contact with the crystallines belong to the Damuda series and probably to the Raniganj stage. The boundary eastwards from Bichiadol is taken from Mr. Smith's survey. It is not possible to make out from this whether the boundary is faulted or not. In the eastern part of it the sandstones are described as resting unaltered on the gneiss between Deosar and Deora; further west, between Pipri and Maoli, there is said to be a good deal of alteration and induration at the contact.

I have seen this junction at two places only. North of Ujaini (a short way off the map) the bottom bed of the Damudas was a breccia of quartz and felspar, evidently the *débris* of a pegmatite of quartz and pink felspar which is intrusive in the crystallines close to the boundary. The other place was near Bichiadol, where the sandstones are found turned up to a dip of 70° to south by east and are considerably indurated. It seems that the boundary is faulted to near the Mohan and eastwards of that natural.

True nature of boundary.

The western portion of the boundary appears to be faulted and in this area there are two small outliers of Talchir rocks. The first of these which was discovered by Mr. Smith rests in unconformable contact on the transitions in the valley of the stream flowing northwards from the village of Tal to the Gopat. The second lies to the east of Tal, and is bounded on the north by the crystallines and the south by the Barakars. This country has been carefully examined by

Mr. Vredenburg, and as the section is valuable as indicating the true nature of the boundary faults of the Gondwanas in this region, it may be reproduced with advantage.

The boundary with the Archæan gneiss was examined for a short distance along the north-western part of map 476. It presents some very peculiar features. It is almost rectilinear, and all these stages of the series in turn abut against it.

Neither original limitation nor ordinary faulting will account satisfactorily for all the features observed ; for not only do the three divisions severally abut against the boundary, but they occur in such close proximity to one another that they must be considered unconformable, or else they all three of them thin out along the same line, which would be inexplicable. At the same time one good contact shows the Barakar beds resting upon the gneiss.

On the supposition that there is here no geological feature of an exceptional character, we may consider which of the three possible suggestions, or whether any of them will account for all the facts observed. These three explanations are: (1) original limitation ; (2) an ordinary fault ; (3) unconformity.

If the rectilinear shape of the boundary and the manner in which it cuts off the several formations are to be accounted for on the supposition of original limitation, this must be of the nature of a cliff—of an inland cliff, moreover, since the Gondwanas are land deposits. Inland cliffs, even when formed by some very regular feature such as the scarp of a very evenly dipping series of beds, are seldom strictly regular ; and in the case of a heterogenous and complex series like the Archæan gneiss, it is difficult to realize how the formation of such a rectilinear feature would be possible. Even supposing it has been given rise to by some unknown agency, the explanation does not account for the fact that the different stages which appear perfectly conformable over enormous areas should suddenly become unconformable along this boundary, and with dips undisturbed within a few hundred yards from it, the rocks remaining sometimes horizontal up to the very contact with the gneiss.

This sudden apparent unconformity will not be accounted for either by an ordinary fault, however well this would explain the rectilinear shape of the boundary and a number of other features, such as the low, undecided dips, the beds dipping just as often towards the boundary as away from it. Lastly, there is the fact already mentioned that in the river near Tal a natural junction may be observed between the gneiss and Barakars, the Talchirs being absent.

It need hardly be added that the supposition of an unconformity, while it would explain the proximity of the various stages, would still leave the question of the shape of the boundary quite unsolved.

It is the consideration of these various peculiarities which has led me to interpret the features observed as the result of a subsidence contemporaneous with the deposition of the beds. During the whole time that the subsidence lasted, it would seem that different movements never ceased taking place along this particular line, or at least along several parallel lines in very close proximity to one another, which would account for the slight irregularities observed, such as the natural junction of the Barakars near Tal.

The description of the line of boundary may appropriately commence with this exposure.

The contact of the Gondwanas with the Archæan gneiss is exposed at Tal in the Kandas river, just below its confluence with another tributary from Kachra and Ponri.

The Gondwana rocks are thick beds of sandstone with much decomposed felspar, resting upon a sloping surface of gneiss. The strike of the boundary at this particular point is 25° E. of N. The dip is insignificant, not exceeding 4°. The strike of the foliation in the gneiss is 70° E. of N.

This natural junction is not in disagreement with the existence of a fault, if it be conceded that the fault was partly simultaneous with the deposition of the beds.

Suppose a fault takes place before the deposition of the sedimentary strata has commenced. If it is on a land surface subjected to ordinary conditions of atmospheric erosion, the wall of the fault will not remain as a cliff, but will be simultaneously denuded. If the

area then becomes one of sedimentation, the figure of the section will be thus: (Fig. 11.)

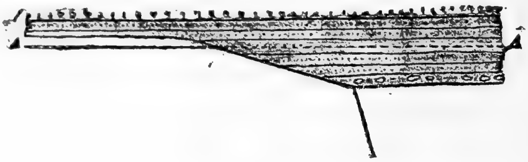


Fig. 11.

If the effect of the final cycle of erosion is to remove the rocks as far as the line AA, the conditions of the boundary will be analogous to those observed in the Kandas at Tal.

Yet the case is not quite similar, for the beds exposed should be the lowermost ones, the Talchirs, while they present the characters of the Barakar sandstone. Instead of supposing the erosion to come to an end we imagine the movement along the fault to continue, or a parallel fault to originate: (Fig. 12.)

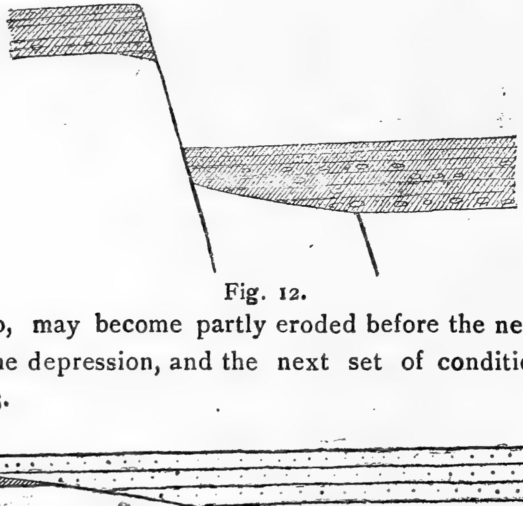


Fig. 12.

This, too, may become partly eroded before the new sediments have filled the depression, and the next set of conditions may be as in Fig. 13.

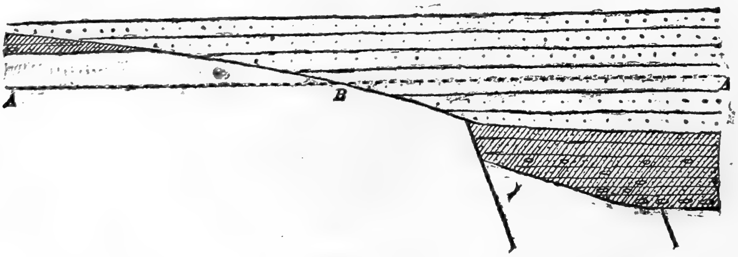


Fig. 13.

Again, supposing denudation to reach the line AA, we will get at B conditions exactly answering to those observed at Tal. If besides we imagine, to the lefthand side of the diagram, a very slight syncline, or small depression in the original floor of deposition, the similitude will be complete; for this would give rise to a small outlier of the Talchirs, just as occurs north of Tal.

The fault shown on the diagram as older than the Talchirs is not needed, as it was imagined merely for the purpose of making the explanation clearer. An additional fault is, however, needed to the right of the diagram in order to sufficiently lower the level of the Mahadevas, as these abut against the boundary a very short distance away from this point, at Kachinar.

The general structure of the section at Tal would therefore be thus:

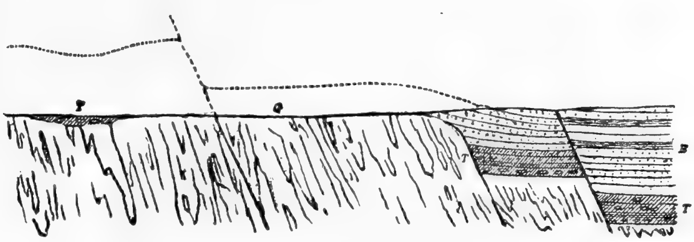


Fig. 14. Section at Tal. *T*, Talchir; *B*, Barakar; *G*, Gneiss.

The existence of the Talchir outlier combined with the fact that the Mahadevas themselves are faulted gives a minimum value for the throw of the fault, looking upon the several step-faults as one; the value should be estimated as at least equal to the thickness of the Talchirs and Barakars, *plus* several hundred feet to account for the thickness of Mahadevas affected.

East of the contact just described, the rocks are concealed by alluvium. At Kachinar, in the river that flows from Maraich just above its confluence with the Kandas, some Barakar beds are seen dipping 10° W. of N. at 23°. The hills east of Kachinar consist of Mahadevas, and it is these that are exposed in the same river higher

up than the last-mentioned exposure. Here the dip is 15° W. of S. at 30°; the gneiss is exposed a few yards to the north, but the nature of the actual contact is not seen. The beds along the boundary continue to consist of Mahadevas for a length of over half a mile; then a small basic dyke occurs in that same position.

East of this dyke the rocks are again much concealed; some Barakar beds are seen dipping east at 10°. The next rock exposed belongs to the Talchir stage. The dip of the beds is 70° W. of S. at 44°. The rocks exposed in the river-bed are laminated micaceous sandy shales interbedded with a clayey coarse sandstone of a deep greenish-blue colour, and containing a multitude of pebbles varying from mere sand-grains up to a foot in diameter. Many of these consist of gneiss similar to that exposed in the neighbourhood; the majority are derived from the Bijawars. Some pebble-beds consist of a conglomerate partly formed of red jasper fragments, and are consequently newer than the Bijawars, possibly Vindhyan. The ice-scratched surfaces are conspicuous.

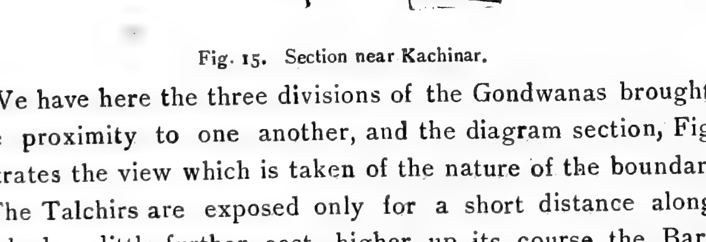


Fig. 15. Section near Kachinar.

We have here the three divisions of the Gondwanas brought into close proximity to one another, and the diagram section, Fig. 15, illustrates the view which is taken of the nature of the boundary.

The Talchirs are exposed only for a short distance along the river-bed; a little further east, higher up its course the Barakars interbedded with carbonaceous shales once more make their appearance. They dip 20° E. of N. at 10°.

Notwithstanding the great irregularities in the amount of dip,

the boundary remains practically rectilinear, the strike being parallel to the foliation of the gneiss.

North of Maraich the Mahadevas again came in contact with the boundary whose faulted nature is here very clear. It runs along the crest of a tall ridge whose southern slopes consist of Gondwana rocks of the Mahadeva type, while the northern portion is made up of a totally different rock which has been variously described as "quartz reef," "jasper," "hornstone-breccia," and the true nature of which has not yet been made out. It often coincides with the Gondwana boundary, but may be only a coincidence, due to the fact that the Gondwana boundary itself follows the direction of foliation of the gneiss, which is the general strike of all the other geological features.

The relation of the Gondwana sandstone with respect to this siliceous rock is not one of ordinary superposition, for the dip does not in any way coincide with the slope of the hill, instead of which the strata lie nearly horizontal. The section here is such as is represented in Fig. 16.

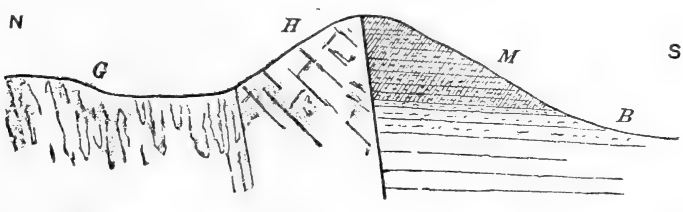


Fig. 16. Section north of Maraich. *B*, Barakars; *M*, Mahadevas; *H*, Hornstone-breccia; *G*, Gneiss.

Unless we suppose that the rock has been deposited against a pre-existing cliff, we are bound to admit that here again it is faulted.

East of this hill of peculiar structure, the rocks in the high level plain of Maoli are typical Barakars, often interbedded with carbonaceous shales; they frequently lie horizontal, or if they have any appreciable dip, the strike is quite at variance with the general strike of the boundary. Here again a basic dyke runs along a portion of the boundary.

East of Maoli, at Bichiadol, there is an exposure of beds only a few yards away from the gneiss; they are highly crushed and disturbed, dipping 40° W. of S. at 70°.

East of the last-named point the line of separation between the Barakars and gneiss can always be followed with very near approximation. The actual boundary is often marked by a band of the peculiar "quartz-reef," or "hornstone-breccia." At one point there is a tall narrow range of Mahadevas; but it is scarped on all sides and of the nature of an outlier; yet the boundary occurs a very short way north of it, and as the dips in the rocks are generally low or inappreciable, there must be a fault as shown in Fig. 17 in order to bring the gneiss almost on a level with the base of the Mahadevas.

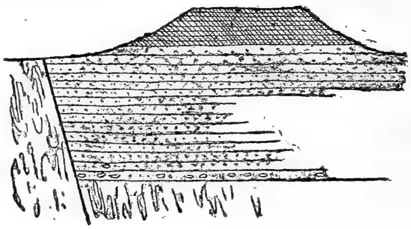


Fig. 17.

I have not followed the boundary further east. Whether the explanation given to account for the observed facts be correct or not, it is well established that along all this line the junction is nowhere of a normal character, that in several instances faulting is evident, and the main feature of the junction is that of a fault.

CHAPTER IX.—COUNTRY NORTH OF THE SON AND WEST OF LONG. 82° 30′ E. (P. N. DATTA.)

Crystalline area.

Crystalline rocks.—There is an area about Saria and Kubri extending eastwards as far as the mouth of the Banas river, which between the basal beds of the lower Vindhyans on the north and the Son on the south shows crystalline rocks (gneiss) occupying the ground. It is upon this crystalline floor that the lower Vindhyans were deposited here.

Junction of the lower Vindhyans with the gneiss about Rimar.

The junction of the lower Vindhyans with the gneiss, which is well exposed at the point south-west of the Rimar village where the Son cuts across the range formed by the basal quartzitic conglomeratic beds of the lower Vindhyans, is well traceable from near Rimar as far as the mouth of the Banas river, with the exception of the neighbourhood of Bakura, where a thick spread of alluvium occurs. By Rimar the conglomerates are seen dipping N. W. by N. at 65°, while the gneiss exhibits a foliation-dip of 78° to S. by E. The gneiss as exposed here is a perfectly foliated rock. Associated with it occur here also bands of hornblende schists.

Intrusion in the gneiss.

Here one mile S. W. of Kaithaha, near Saria, I found, on the bed of the Son, a coarsely crystalline rock intruded, evidently as a dyke, in the gneiss. This find is of interest, inasmuch as the rock belongs to the olivine-norite group of the dyke-rocks of South India and the lava-flows in the Cuddapahs. Taken as the type of the group, it has been fully described by Mr. T. H. Holland (Records, G. S. I., Vol. XXX., pt. i, pp. 20, 21).

LOWER VINDHYANS.

I.—BASAL STAGE.[1]

Basal stage.

This (the basal) stage is formed of the lowermost beds of the lower Vindhyans, and includes Nos. 1 and 2 of Mr. Mallet's sub-divisions of the lower Vindhyans.

[1] The four-fold classification of the lower Vindhyans, *viz.*, into the Conglomeratic(Basal), Porcellanic, Kheinjua and Rohtas stages, was first proposed by me in the Notes on Rewah in 1895. Rec., Geol. Surv. Ind., Vol. XXVIII., pt. 4, p. 145.

Extent of area exhibiting Basal beds in this neighbourhood.

The small patch of ground about two miles S. by E. of Deora, or on the left bank of the Son due north of Ghusra, together with the narrow strip of land commencing about a point Long. 81° 16'·5 E., Lat. 24° 10' N., and running north-east as far as the confluence of the Banas with the Son, is all the area that is occupied here north of the Son by the beds of the basal stage.

Limestone at top of Basal stage: its changeableness.

In the western parts of this area the top of the basal beds is formed by a limestone, which shows a good deal of variation even within a short distance. For instance, on the left bank of the Son, ½ mile S.-W. of Bakaili (or 5½ miles S.-E. of Ramnagar) the rock is light grey, non-crystalline, fairly pure and in beds of moderate thickness; while the same band of limestone presents at a point a little over 2 miles south-west of the last-named outcrop totally different characters—the rock being here mostly dark grey, crystalline, much veined with calcite and with the bedding obliterated. Traced north-eastwards the rock is highly siliceous by Mahadabur, but is purer again by Kusma. The band narrows down considerably by Rimar, dying out by Bela and replaced by a white earthy shale by Bartona. Eastwards of this no limestone is traceable in this horizon, that is, in this little area, except by Kanwari (one mile E. of Ludbad), where a calcareous outcrop to the extent of a few square yards is visible.

General characters of the Basal beds near Rimar.

The rocks between this limestone which forms the top of the basal stage here and the very bottom beds (conglomeratic) which form the range running N.E.-S.W., south of Rimar and Bela, are not very well exposed, but detailed observations show that in this neighbourhood the limestone seems to pass down into a dark bluish earthy rock ferruginous in places. Shaly sandstone with quartz and ferruginous bands and quartzitic sandstone, light to dark grey and fine-grained to coarsish, are next seen, while lower down ferruginous calcareous beds with pale greenish shale passing down into a greenish argillaceous shaly sandstone come in close above the quartzite which forms the

range between Bela and Saria. This quartzite which is thick-bedded, compact and hard, and reddish white in color, has hardly any pebbles in its upper part, but becomes conglomeratic in the lower parts, the pebbles here being of white and reddish quartz, reddish quartzite and red jasper, and constitutes the lowermost beds of the Vindhyan basin here.

II.—Porcellanic Stage.

Porcellanic stage.

Above the basal stage come in the Porcellanic shales.

Traced from near Ramnagar.

Beginning at a point on the Son about 6 miles south by south-east of Ramnagar, the Porcellanics run on north-westwards as a fairly thick band. By Marjatpur the outcrop is thicker, but beyond this point it contracts again and the beds assume a more easterly strike and are well traceable, forming as they do the hilly ground by Amlai and Garhara eastwards. In the neighbourhood of Baghar and Dembha, however, there is a good deal of alluvium concealing the beds. Just east of Dembha occurs the Son crossing the Porcellanics at right angles to their strike.

Well exposed near Deora.

Nature of the beds composing the stage.

A little to the south of Deora, on the Nagour, in the western parts of this area, the Porcellanics are well exposed. Along with the typical rock,—*i.e.*, the porcellanic shale which is characteristically greyish white and is often composed of laminæ of various colours, such as grey, yellowish, white and blackish, and is generally thin-bedded,—occur, interbedded, making up not an inconsiderable portion of the entire bulk, ordinary argillaceous shales and sandstones of a pale greenish hue. Intercalated with the above also occur beds of a homogeneous clayey rock and a rock of a dark to bluish grey color, much resembling a limestone, but non-calcareous. Along with these beds we also find a rock which is more compact, harder, coarser, thicker-bedded and more distinctly

The "Trappoid" rock.

bluish and weathering light yellowish brown. Quartz-grains, mostly rounded, with sparsely distributed felspar crystals, make up the rock. These hard, coarse beds do not occur entirely and purely by themselves, but often have finer-grained shales interbedded with them. Following the Porcellanics down the Nagour, these harder beds are first met with just at its confluence with the Son and can be well followed up the Son along its left bank, until finer porcellanic shales forming the lowest beds of the stage are come upon again. These harder beds are difficult to map, as they do not form a pure band by themselves nor keep to the same position, but are, on the other hand, very inconstant and variable. They are, however, more or less traceable all the way from Baikona to Marjatpur and from Marjatpur by Amlai to Garhara. Between Garhara and the Son one does not see much of the rocks owing to the preponderance of alluvium.

Limestone interbedded in the Porcellanics.

By Jhinna and Marjatpur a thin band of limestone occurs towards the upper parts of the Porcellanics, intercalated with the typical porcellanic shales, effervescing freely with acids. This limestone passes gradually and imperceptibly into the shales above and below, the passage rock effervescing less and less until the bluish rock into which the limestone eventually passes does not at all effervesce with acids and seems entirely free from calcareous matter, though in look and appearance it would be the easiest thing for anybody to mistake it for a limestone.

III.—Kheinjua Stage.

Kheinjua beds.

Overlying the Porcellanics there occurs a mass of alternating shales and sandstones with occasional bands of limestone. These shales and sandstones, though they naturally vary somewhat as they are traced from the base upwards, still, taken together, present a relationship and unity of character to entitle them to rank as of one group or stage, and this

Their position defined.

including all the beds from the upper boundary of the Porcellanics as far as the commencement

of the limestone—the Rohtas limestone—occupying the topmost part of the lower Vindhyan beds. To this mass of argillaceous and arenaceous beds—*i.e.*, between the Rohtas limestone above and the Porcellanics below—the term "Kheinjua" has been given. It was first so applied by me in my notes on the Son Valley.[1]

The Kheinjuas sub-divided into 8 zones.

Sub-division of the Kheinjuas.—The beds thus treated as forming one independent stage are, however, consisting as they do of alternate shales and sandstone with limestone, susceptible of arrangement into distinct zones. As the superficial deposits prevail largely over the eastern parts of the area under consideration, the Kheinjuas are consequently better exposed and studied in the western parts. Taking the neighbourhood of Ramnagar for a typical section, they (the Kheinjuas) were found, on examination, to be divisible into 8 zones[2] :—

(In descending order)

Zone VIII.—Argillaceous shales—

Containing calcareous concretions and fair abundance of limestone beds; arenaceous element insignificant and small where not almost entirely absent.

Ramnagar stands on these.

Zone VII.—Limestone band—

Limestone pure; no calcareous concretions as a rule; no arenaceous or argillaceous element present.

This is the limestone band between the two villages of "Khajuri" of map, south-east of Ramnagar.

Zone VI.—Shales—

Arenaceous and argillaceous, with thin-bedded sandstone; ripple-marked; altogether free from calcareous beds.

On these stands the southern one of the two villages of the name of "Khajuri" of map.

Zone V.—Limestone with shales—(or rather shales with some limestone).

Shales reddish, sometimes calcareous, at other times not often forming bulk of the zone. Limestone very impure and interbanded with sandy layers showing ripple-marks; sometimes brecciated and contain cherty and quartzitic inclusions.

[1] Rec., Geol. Surv. Ind., Vol. XXVIII., pt. 4, p. 145.
[2] Rec., Geol. Surv. Ind., Vol. XXVIII., pt. 4, p. 146.

This zone is exposed on the Nagour Nadi (stream) at ¾ mile south-east by south of the southern village of "Khajuri" of map.

Zone IV.—Shales . Arenaceous and argillaceous; much ripple-marked; with thin-banded sandstone, often quartzitic.

Zone III.—Sandstone . Thick-bedded, grey and white, compact and quartzitic. This forms the scarp one mile north-west of Deora.

Zone II.—Limestone with shales—

Limestone purer than No. V; shales little developed by Deora but better developed and seen by Sukwari at the junction of the Andhiari with the Mahanadi (Lat. 24° 5′, Long. 81° 2′); here the shales are argillaceous, greenish and non-calcareous and free from ripple-marks.

This is the limestone band seen just at the southern foot of the sandstone scarp one mile north-west of Deora.

Zone I.—Shales and sandstones—

Shales greenish and laminated; sandstones generally thin-bedded.

Deora stands on these.

Zone I further sub-divided.

In the neighbourhood of Deora the beds of zone I are further sub-divisible, in descending order, into:—

(*a*) A thin band of yellowish grey quartzitic sandstone, moderately fine-grained, passing downwards into a finer-grained darkish grey rock.

(*b*) Finely laminated pale greenish argillaceous shales, with occasional arenaceous bands. Well exposed on the Nagar Nadi just above and by the Temple at Deora.

(*c*) A thick band of sandstone, in places thick-bedded and quartzitic looking and light grey to yellowish in color, first appearing a little south of the Temple at Deora. This forms the very base of the Kheinjua stage, resting on the Porcellanics below.

Further details relating to the different zones of the Kheinjua Stage.—

The Kheinjuas. Sub-division of zone I not traceable far.

Zone I.—The sub-divisions of this zone (*i.e.*, into the sub-zones *a*, *b* and *c*) as indicated above, from the section near Deora, are not traceable far south-west or north-east from Deora, because, on the one

hand, exposures are bad, a good deal of the country lying under cultivation or the rocks being otherwise so ill-exposed or concealed as to render minute examination of the ground difficult or impossible; and on the other hand, the sub-zones themselves do not seem to retain for any distance their individual characters owing to rapid lateral change. So the attempt to map these sub-zones was given up, the whole of the beds being classed as one main zone and mapped as such.

Zone I persistent.

Although the shales and thin-bedded sandstones constituting the Zone I exhibit lithological variations from place to place, they seem on the whole to be persistent over the entire area, though they may be lying a good deal concealed in some localities, as on the east, or found to have lost much of their thickness, as seen towards the west.

Zone II.—Limestone with shales.

Character of the beds.

The shales are argillaceous, well-laminated, greenish, non-calcareous and free from ripple-marks.

The limestone in its look and color is not often unlike that of Zone V, but is altogether much purer.

The zone as traced from junction of the Andhiari eastwards.

Beginning on the west, this zone is well seen at the confluence of the Andhiari Nadi with the Mahanadi River (Lat. 24° 5′ N., Long. 81° 2′ E.). Here a considerable quantity of the green shales occurs associated with the limestone. The band is well traceable from here, with a strike east by north, along the Son and occupying most of the river-bed for a distance of about 10 miles, after which it leaves the Son and runs almost due north-east along the southern foot of the sandstone scarp one mile north-west of Deora. By Deora the zone has very little shale in it, beds of limestone making up almost the entire thickness.

The limestone dies out by Ucheyra.

After crossing the Nagour Nadi the limestone band begins rapidly to lose in thickness and to die out by "Ucheyra" of map. From this point eastwards as far as the neighbourhood of Ghungta no limestone is visible in this horizon (a good deal of the intermediate country, it must be remembered,

lies under alluvium). But at ½ mile west by south of Ghungta (western) a very thin calcareous band makes its appearance, and is traceable north-eastwards by Ghungta, Jhala and Ghidaora, where a double curvature, indicative of the flexure which the rock-mass has here undergone, is exhibited by the band. The band is lost sight of under alluvium by the easternmost village of Ghidaora, and continues so until we reach a point (Lat. 24° 24'·5, Long. 81°41') where, about one mile south-east of Missirgama, a thin band, occupying about the same horizon and probably a continuation of the band seen on the west, appears again and is traceable east by north by Dowara as far as Pawa. East of Pawa it is difficult to come upon any calcareous band in this horizon except a patch here and there, as between Bhitari and Lakhaora and also south-east by south of Lakhaora, until we come near to Patpara, whence a thin band is traceable to a point about ⅓ mile south of Koludi. Eastwards from here and to the limits of the area under consideration the ground is so thickly spread over with alluvial and other superficial deposits as to render hopeless any attempt to follow the band further.

Calcareous band by Ghungta, etc.

Limestone band by Patpara.

On the stream that falls into the Son just west of Sahaol are exposed, close to its mouth, a few beds (3 or 4) of a cream colored limestone, and a little limestone is also seen on the left bank of the Son just south of Sahaol. These may be of about the same horizon as Zone II. But it is difficult to assign with any degree of confidence to their true position any isolated exposures like these, so far away from the main band. That the little limestone seen on the stream ¾ mile south-west of Sahaol may not, on the other hand, extend far but probably dies out quickly, appears likely from the rapid thinning out observed in these limestone beds even within the width of stream itself.

Limestone at Sahaol.

Zone III.—The sandstone forming this zone is grey to white in color, generally fine-grained, hard, compact and quartzitic. From its hard, compact and quartzitic character, which has enabled it to resist denudation better than

Sandstone quartzitic.

any of its neighbours, it has been able to give rise to that prominent range of hills, which commencing from the Andhiari Nadi (the westernmost limits of the area under report), 2½ miles almost due west of the confluence of the Mahanadi with the Son (Lat. 24° 5′ about, Long. 81° 3′), stretches east by north along its left bank, forming a great and prominent scarp overlooking the Son, till it reaches a point due south of Ramnagar where it leaves the Son, and turning further north continues to keep a steady north-east course. By Marjatpur the zone is much thinner, and as it is followed eastwards (the course of the range here becomes east by north again) it still more loses in thickness, ceasing to exist as a distinct thick-bedded hard quartzitic band by Raidooria. Eastwards of this we certainly have a range of hills, though less in height and prominence, in about this horizon, composed of shales and thin-bedded sandstone. Such, for instance, is the range that we find running east by north from a point ⅓ mile south of Bardela, then north-east (at 1½ miles south-east of Rampur) and then after describing a curve about 2 miles east of Rampur turns east by north again and runs between Duari and Ghidaora, by Kataoh, Kua, Churhat and Dowara, beyond which it is split up into still smaller and minor ranges. Such are the low hills (striking W. by S.—E. by N.) about ½ mile south of Chilari and Lakhaora and by southern Patpara. Between Patpara and Koludi even these minor hills disappear. Alluvium predominates so from here eastwards as to render it impossible to mark the traces of even a continuation of the hills observed on the west. As already mentioned, we certainly have, east of Raidooria, where the quartzitic band of sandstone ceases, a smaller range of hills which we can follow, as shown above, continuously as far as Dowara, it splitting up, as already noted, into minor ranges beyond that point. The reason why this range cannot be mapped as continuation of Zone III is twofold, namely, first, the rock composing this eastern smaller range or ranges is not a hard

Forms a prominent scarp.

Ceases to run as a defined range beyond Raidooria.

Why difficult to trace the zone beyond Raidooria.

quartzitic sandstone but thin-bedded or shaly sandstone and shales; and secondly, near the typical section by Ramnagar, another range of hills, less prominent and less high, occurs formed of shaly thin-bedded sandstone and shales belonging to Zone IV; and we cannot be sure, in the absence of organic contents, whether the chain of hills we have traced from Raidooria and by Rampur, is formed of thin-bedded sandstone which belongs to Zone IV or which is an extension, as result of lateral change, of the quartzite of Zone III.

The scarp south of Ramnagar.

The scarp referred to by Mr. Mallet as occurring near Ramnagar, and truly "rivalling in magnitude the Kymore range itself," is formed of this hard quartzitic sandstone of Zone III. This scarp sandstone probably does not belong to Mr. Mallet's sub-division No. 8 as stated in the Memoir,[1] but really to his sub-division No. 6. For if the limestone band exposed on the Nagour Nadi $\frac{3}{4}$ mile south-east by south of "Khajuri" of map is sub-division No. 7 limestone of Mr. Mallet's (=our Zone V), these beds forming the Kheinjua scarp, which *underlie* the limestone, are necessarily older, and not younger.

Shales much ripple-marked.

Zone IV.—These are the much ripple-marked shales (arenaceous as well as argillaceous) that come above the quartzitic sandstone of Zone III, and are underlaid by a calcareous zone (Zone V).

So long as Zone III is traceable, the lower boundary of Zone IV is of course clear. But where Zone III is no longer definable, it is not practicable to separate the thin-bedded sandstone and shales of Zone III from those of Zone IV. The overlying calcareous zone (Zone V) being however fairly persistent over a wide area, the upper boundary of Zone IV is thus far better defined than the lower, and will be best followed when the course of Zone V is indicated.

Zone V.—This is a band of limestone with shales, and corresponds to sub-division No. 7 of Mr. Mallet's.

Limestone ripple-marked.

The limestone is, as a rule, very impure, being often brecciated and cherty. A noticeable feature about this limestone is its ripple-marked character, the ripples

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 40.

having been preserved on layers of sand intercalated between thin bands of sandstone, well seen about Sulkma. Associated with the limestone, in its upper part, is a highly ferruginous rock presenting, when weathered, a highly complicated honey-combed structure, utilizable as a source of iron.

Iron ore.

The zone as traced from Sulkma eastwards.

Commencing at the western extremity of the area under discussion, the limestone outcrop on which Sulkma stands is the limestone of this Zone V. This is followed eastwards by Kudri to Dueria, then east by north as far as the longitude of Ramnagar (Long. 81° 11'·5) when it turns north-east, and this course is kept up to near Naogama. The zone has much thinned out by this time and is only traceable as a very thin band striking E. by N. by close south of Khoomarha, a little south of Dangarha, by Raidooria, by Rampur, and then after a double curvature near Rampur, runs by Raikhor, Kua and Churhat, and is well traceable as far as Lakhaora, east of which alluvium steps in and the band is no longer possible to follow. (The limestone visible by the tank of Bargama is probably the outcrop of a flexure in the main band). So by Patpara and Koludi and eastwards the band ceases to be connectedly traceable. The small calcareous outcrop by the tank of the southern village of Pahari and by the western tank of Hinaoti, together with one between Lillwah and Sahaol mark in all probability the eastern continuation of Zone V. Between Sahaol and one mile east of Bhaghor no limestone is visible about this horizon, but from the latter point a thickish band is observable by Bardi, Barhat, Khaira and as far as Gangi. The band is quite thickish as seen exposed on the stream a little to the west of Gangi. But it is difficult to follow it nearer the village. About ¾ mile south-east by east of Gangi and close to the right bank of the Son some calcareous beds are seen with a local high dip to the south indicating the disturbance to which the beds have been subjected hereabouts. This exposure, however, shows nothing of the thickness of the limestone band seen just west of Gangi, and so whether it marks a continuation of the

Limestone band by Bardi, Barhat, etc.

western band, or is only some extraneous calcareous beds in the Kheinjuas, one cannot be quite sure.

Zone VI.—These are the shales (argillaceous and arenaceous) with some sandstone generally thin-bedded, that come in immediately above the calcareous Zone V. The shales are often finely laminated and ripple-marked, but the ripple-marking is by no means so abundant here as in the shales of Zone IV. The zone is entirely free from calcareous matter.

Ripple-marks not so abundant as in Zone IV.

This zone is, as we have seen in our typical section by Ramnagar, overlaid by the limestone band of Zone VII. Thus its upper boundary is also well-defined so long as the limestone of Zone VII is traceable, and this is so from the western limits of our area (Long. 81° 0′) to near Rampur (Long. 81° 31′). East of this point Zone VII is no longer traceable; superficial deposits predominate to such an extent in these parts that it is impossible to tell whether the limestone of Zone VII has quite died out here or is merely concealed by the alluvium. Hence in the eastern parts of the area, Zone VII being no longer traceable, the shales of Zone VI cannot be mapped separately from those of Zone VIII; for though their characters are such that they could be easily separated on a clear section, superficial deposits here cover them both alike, rendering any separation impossible.

Difficutly of tracing the band.

Zone VII.—It being a pure limestone band with no sandy or clayey elements in it and altogether purer than the limestone of Zone V or II, is easily distinguishable from the two latter.

Easily distinguished from the limestone of Zone V or II.

This is the band that runs by just south of Nando and Mirgaoti and between the two villages of "Khajuri" of map (one mile S. E. of Ramnagar), and from here, though much concealed under alluvium, it no doubt runs but only as a very thin band, with a general strike of W. by S.—E. by N., as far as the neighbourhood of Rampur. The second band of limestone exposed on the Marhawal Nadi from its mouth (*i.e.*, little short of a mile up the stream from its junction with the Son, Lat. 24° 19′, Long. 8° 30′) is the limestone of Zone VII.

The zone as traced from Nando.

It seems to die out shortly, or is not at any rate traceable further.

Characterised by shales with calcareous concretions.

Zone VIII.—These are the well-laminated argillaceous shales that immediately underlie the Rohtas limestone.

These shales have characteristic calcareous concretions developed in them, and have also frequent beds of limestone intercalated in them and are besides almost free from arenaceous beds, points which distinguish the shales of Zone VIII from those of any of the underlying zones of the Kheinjua stage.

As for the calcareous concretions, although they certainly characterize the argillaceous shales of Zone VIII, occurring more or less through the entire thickness of it, they are not confined to this zone alone but are found also, and in some abundance too, in some parts of the Rohtas limestone, as for instance, near Marwar (south-east of Mankaihri), Deori (west by south of Gursari), etc., and those that occur in the Rohtas are quite indistinguishable from those of the Kheinjua beds.

Occurrence of quartz crystals.

Crystals of quartz often of good size and beauty occur in places in fair abundance in the shales of this zone. From the state of exposure of the beds it is not possible to say if they are confined to any particular set or sets of beds. On the left bank of the Son, north-west by west of Bardi, for instance, is a good exposure of these shales with the quartz crystals.

IV.—ROHTAS STAGE.

The stage is made up entirely of limestone.

Rohtas Stage.

This is the limestone that comes in immediately underneath the Kaimur sandstones and shales of the Kaimur scarp and forms the youngest of the four stages constituting the lower Vindhyans.

Comprises Mallet's subdivisions Nos. 9, 10 & 11.

This stage comprises Nos. 9, 10 and 11 of Mr. Mallet's subdivisions. The shales of No. 10 have not been observed in the area under notice; while the

limestone of sub-division No. 9 is so like that of No. 11 that it is impossible to separate one from the other. Thus all the limestone has been classed as forming one stage, the Rohtas.

Rock thin-bedded and flaggy.

The rock is a pure grey limestone, somewhat pinkish or salmon-colored in places in the upper part and generally very thin-bedded. This flagginess obtains throughout the thickness of the stage, thick beds being rare.

Calcareous concretions.

The limestone towards the base of the stage exhibits a tendency towards concretionary character, circular to oval concretions of carbonate of lime, often of great regularity and beauty, being in places abundantly developed.

Quartz crystals.

Crystals of quartz have in some places been developed in drusy cavities in the limestone.

Local bending and contortion of the rock.

The sudden and extreme bending and contortion, also equally shared by the upper beds of the Kheinjua stage, which the Rohtas has locally undergone, forming a remarkable and conspicuous feature in these beds, has been noticed by Mr. Mallet.[1] The topmost beds—those by the junction with the Kaimurs—show, however, no evidence of such disturbance.

The stage not divisible.

The limestone being of a uniform character from the top to the base, the stage is not susceptible of any further sub-division.

Mr. Mallet's Sub-division No. 10 not observable here.

As already stated, sub-divisions No. 9 (limestone), No. 10 (shales) and No. 11 (limestone) of Mr. Mallet's are comprised in our Rohtas stage. But nowhere in the area under examination could I come upon the shales that form sub-division No. 10.[2] Though fairly good exposures are available in the western parts of the area, no shales were there observable in the limestone except here and there to the thickness of 6 to 9 inches or so. As regards the eastern parts of the area under notice, though alluvium prevails here to a very considerable extent

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 43.
[2] Mem., Geol. Surv. Ind., Vol. VII., pp. 28, 42.

the stage is apparently composed of thin-bedded limestone of the same kind and character as on the west, and no indications of a band of shales such as would correspond to No. 10 of Mr. Mallet's sub-divisions could anywhere be clearly discovered. These shales are, however, stated to occur between Rajgurh and Rewasin Hill.[1] That Rajgurh is probably a misprint for Ramnagar would appear from the occurrence in the maps supplied for survey of a locality of the name of Ramnagar in about the identical position of "Rajgurh" in the map accompanying Mr. Mallet's Memoir. Taking Ramnagar and Reiwas Hill, then, for "Rajgurh" and "Rewasin" Hill, one can only remark that in this area hardly any clear exposures of even the upper beds of the stage are obtainable, to say nothing of an intercalated band of shales in them. At the foot, however, of the scarp by Baghawa, Diholi and a few other localities, I certainly observed *débris* of what looked like argillaceous shales; but as in none of these places could I discover any indications of lamination or bedding in them, it was not possible to make sure whether what was observed was the *débris* of the shales washed down the slopes from above, or really shales *in situ*.

Kaimur-Rohtas junction.

Relations of the lower Vindhyan system.—The nature of the Kaimur-Rohtas junction has rather been a matter of doubt and uncertainty, for while some have asserted, though rather feebly, that there might not be much of an unconformity here, others have, on the other hand, strongly maintained that the break indicated at this junction is so great as to justify the full and complete separation of the two series of beds that meet at this point.

Drawbacks to the close examination of the junction.

Over a good extent of the area under review circumstances were anything but propitious for a close scrutiny of the junction of the Rohtas with the Kaimurs above. For the junction runs along the Kaimur scarp either at or by its foot or a little way up the scarp, positions exceedingly favourable for the gathering of *débris* of shales

[1] Mem., Geol. Surv. Ind., Vol. VII., pp. 42, 43.

and sandstones from above, drawbacks of this description being rather greater on the western parts of the area than on the eastern. Still every endeavour was made to see what evidence could be gathered under the circumstances. In the attempt to get at evidence bearing on the nature of the junction I followed it (the junction) with a special look-out for any indications of denudation-unconformity, but I cannot say I succeeded in coming anywhere upon a contact of the Rohtas limestone with the rocks above indicating an erosion-unconformity, though the ground was pretty closely examined wherever and whenever the state of exposure allowed it. The shales (so constantly seen, specially on the western parts of the area under notice) immediately overlying the Rohtas certainly seemed thicker in some places than in others, but whether this was due to the original variability in the shaly deposit, or to denudation of the underlying limestone in places (where the accumulation of shales would thus be greater than elsewhere) before the deposition of the shales, or to local depression in the rim of the basin, which would thus take out of sight some of the lower beds, it was difficult to make sure. Should there have been denudation in the case, the contact between the limestone below and shales above ought to show some evidence of erosion somewhere or other, but I myself never succeeded in finding any exposures demonstrative of such erosion. But this evidence, though of importance so far as relates to the localities of the particular exposures explored, cannot be said to prove and establish the absence of erosion of the Rohtas before the deposition of the superimposed beds for the whole area, inasmuch as I was not able to examine the junction in its perfect entirety. But as regards that much of the junction as could be examined, the indications pointed to the absence of erosion.

No erosion-unconformity observed.

In reference to the relations of the Rohtas with the supra-Rohtas beds as regards dip, no dip-unconformity was anywhere observed either; but wherever there was a clear exposure, the uppermost Rohtas beds were found to be perfectly parallel with the suprajacent Kaimurs.

Perfect dip-conformity with the Kaimurs.

Contortion of Rohtas not prior to the deposition of the Kaimurs.

There is certainly much evidence of disturbance in the beds of the Rohtas limestone, often in close proximity to the base of the Kaimurs, which, however, are quite undisturbed. That the Rohtas limestone might have been disturbed and contorted before the deposition of the Kaimurs is, however, contradicted and disproved by the invariable complete parallelism of the topmost Rohtas limestone with the Kaimurs which has been observed wherever a clear point of junction has permitted an examination.

Sections bearing on the nature of Rohtas-Kaimur junction.

We will now briefly refer here to a few of the sections at the Kaimur-Rohtas junction which bear on the question of the nature of that junction.

The exposures at the Kaimur-Rohtas junction were, as already indicated, few and imperfect, but the following sections among them were thought instructive :—

Gursari Ghat.

Gursari Ghat.—Here the siliceous shales are seen to pass normally into the Kaimur sandstone of the scarp. The junction of the shales with the Rohtas is, however, concealed here.

Hinaoti.

Scarp-slopes by Hinaoti.—The exposure here too is not perfect, but the Rohtas limestone seems to pass into a fine-grained homogeneous shale which, when freshly broken, is green but turns bluish chalky white on exposure to the air. Such a rock is what we should expect to meet with as a passage-rock from a limestone. For a little space up the slopes, above the last-mentioned shale, the ground is covered, but the shales that are exposed a little higher up are somewhat siliceous, and these pass above into the thick-bedded sandstone of the Kaimur scarp.

Passage bed.

Daorahra.

Foot of the scarp slopes, north-west of Daorahra, near Boorgaona.—The homogeneous shale referred to as being met with in the last-mentioned locality is also exposed here. But neither the junction of the

Rohtas with this shale, nor the passage of this rock into the siliceous shales and sandstones above, is traceable here.

Majgama.

Scarp-slopes, north-west of Majgama —The foot of the spurs is occupied by the Rohtas limestone. A little way up (after a short blank) a finely laminated soft shale, white grey to blackish, is seen (the shale is occasionally blackish enough to look carbonaceous). This soft shale passes upwards into a shale somewhat harder, the color being yellowish to brownish grey, with a faint approach to porcellanic look.[1] Beyond this point a talus of sandstone obscures the section, but the thick-bedded sandstone of the scarp is close above.

Reiwas Hill.

Reiwas Hill ($4\frac{1}{2}$ miles north by east of Rampur). At the south-eastern extremity of this hill, although the exact and precise point of junction (Kaimur-Rohtas) is not to be seen, the uppermost Rohtas limestone as well as the shales above are well exposed. Just above the uppermost limestone exposed, a few feet of blank section, covered over with shale-débris, intervenes, beyond which occurs a laminated shale, somewhat blackish in places and very slightly, if at all, siliceous. This shale is succeeded by some more shales which are earthy and somewhat porcellanic. Over these comes in the thick-bedded sandstone (the dip of the limestone as well as of the shales above is N. 15° W., at 11°).

Inference from the above sections.

These sections, we take it, indicate that there is no physical break in the shape of abrupt change in the lithological character of the rocks observable as one passes from the Rohtas to the beds above; but that, on the other hand, the indications all point the other way, namely, that there is a physical continuity in the passage from the Rohtas into the Kaimur beds above.

Sections from the eastern parts of the area.

The following sections are taken from the eastern parts of the area:—

[1] It may be added here that south of Seranga, near Mirgaoti (Lat. 24° 09′, Long. 81° 07′) we find a limestone passing down through a white chalky rock into a porcellanic shaly rock.

Ginaor.

Ginaor.—There are two little hillocks at the foot of the Kaimur scarp by this village. At the eastern extremity of the western hillock is exposed a gentle anticline formed by sandstone (Kaimur), in the centre of which is seen a darkish grey sub-porcellanic rock exactly like that observed in the western parts of the area under notice between the Rohtas limestone below and the Kaimur beds above. This sub-porcellanic shaly rock passes up into a light grey laminated soft shale which is overlaid by the sandstone forming the top-beds of the anticline. This sandstone is the continuation of the lowermost beds of the sandstone exposed on the adjoining Kaimur scarp. The Rohtas is not exposed here, but there is little doubt but that it comes in just below the sub-porcellanic shaly beds. Thus all that we can see here is that the sub-porcellanic siliceous shaly rock passes up into a soft light grey shale which in turn seems to pass up into the sandstone of the Kaimur scarp.

Tikat.

Hillocks by Tikat.—There are three little hillocks here at the foot of the Kaimur scarp. Rising as they do from the alluvium of the plains, these hillocks are seen to be composed of sub-porcellanic siliceous shales which are well exposed on their southern slopes and are capped by thin-bedded sandstone. No marked thickness of the laminated soft shales occurs here, but the siliceous shales seem to be immediately overlaid by the sandstone. The uppermost shaly rock does not seem to be an admixture of argillaceous and arenaceous materials, but while the shale is exceedingly fine-grained and seems argillaceous (though may be somewhat siliceous), the sandstone seems entirely arenaceous and is not very fine-grained. Thus there appears to be here an absence of a true passage of material from the one set of beds into the other. But though this is so, there is a perfect parallelism of bedding between the shales and the sandstone. The Rohtas below the sub-porcellanic shales is not exposed here.

Absence of true passage of material, but beds parallel.

Baghawa.

Baghawa.—The foot of the scarp-slopes north-west of Baghawa exposes sections exactly similar to those near Tikat. Here, at one spot, the topmost layer,

2 inches thick, of the siliceous shale could be traced for a few yards along the junction with a perfect dip-conformity with the overlying sandstone, although in the character of the constituent materials the shale and sandstone were sharply marked off, one being of fine argillaceous material, perhaps somewhat siliceous, and the other purely arenaceous.

Dip-conformity but no gradual passage.

Diholi.—At a point at the foot of the Kaimur scarp, north-west of Diholi, is seen a section quite similar to the preceding, but here the limestone (Rohtas) is exposed in addition, underlying the sub-porcellanic siliceous shales. These shales are very well seen here, being light to dark grey in the lower parts and rather finely laminated in the upper parts. The junction of the sandstone with these shales is as in the preceding section, but the contact of the latter with the underlying limestone is not exposed. The point of interest, however, here is that all the three sets of beds, namely, the Rohtas, the suprajacent siliceous shales, and the sandstone overlying the last, are all well exposed, exhibiting a perfect parallelism of bedding between one another.

Diholi.

Dip-conformity of Rohtas with the overlying shales and sandstone.

We thus find from these sections that while near Ginaor the sub-porcellanic shales pass up into a shale which in turn seems to pass into a sandstone, this latter shale is little developed by Tikat. Throughout the greater part of the area in sheet 474 (*i.e.*, from Long. 82° to 82° 20′), the rim of the upper Vindhyan basin seems depressed, and the Kaimur sandstone comes down to the level of the alluvium of the plains. Eastwards of this point the Rohtas is again visible by the foot of the scarp, but the siliceous shales are no longer traceable, being apparently absent, the result being that the Rohtas is in direct contact with the sandstone of the Kaimur scarp. These last two sets of beds, however, exhibit a thorough dip-conformity throughout.

What these sections show.

From the sections recorded above we are thus, in conclusion, led to infer—

Inferences from the sections recorded above.

(i) That there is a passage from the Rohtas limestone into the

Kaimur sandstone through a homogeneous white shale, as observed by Hinaota, Daorahra, etc., and a sub porcellanic siliceous shale, which itself passes up into the overlying sandstone.

(ii) That the above mentioned shales—the homogeneous white shale, the siliceous shale, etc.,—die out towards the east, and that there is an overlap of these by the Kaimur sandstone which thus rests directly on the Rohtas limestone in the eastern parts.

(iii) That this overlap would explain the abrupt juxtaposition of a coarse rock like the sandstone of the Kaimurs and of a fine-grained homogeneous deposit such as the Rohtas limestone, an abruptness that has hitherto been held to be universal, and as such been insisted on as evidence of unconformity between the lower and the upper Vindhyans, but which appears now to be local and not universal, obtaining over only parts of the area and being replaced in other parts by a gradual passage from the limestone of the Rohtas into the arenaceous beds above.

(iv) That though there is thus an overlap in certain parts by the Kaimur sandstone of the shales that come in immediately above the Rohtas, there is no unconformity between the lower Vindhyans and the upper.

CHAPTER X.—THE COUNTRY EAST OF LONG. 82° 30′ E. (R. D. OLDHAM.)

Lower Vindhyan.

The main area of the lower Vindhyans east of Long. 82° 30′ to the eastern boundary of Rewah territory no longer presents the normal succession seen to the west. The porcellanites can be traced to near the Son at Gangi, though they are much less developed than to the west, and a larger proportion of the beds included in this stage are distinctly shaly.

Section at Hurma.

At Hurma the outcrop of the lower Vindhyans narrows down to not more than a mile in width, and as the section here marks the disappearance of the porcellanite stage, which is only picked up once some 28 miles to the east, deserves detailed notice. Along the south bank of the Son, opposite Hurma, there is an exposure of coarse grained quartzitic sandstone very similar to the basement beds of the lower Vindhyans. Traced eastwards, however, it forms a low ridge which can be traced to an exposure in the stream which flows northwards past Khattai. Beyond this the rock is seen at intervals and can be shown to belong to the transitions and not the lower Vindhyans, both by being associated with slates of transition type and by the exposure of the basement bed of the lower Vindhyans in its neighbourhood.

On the section south of Hurma the basement bed is not seen, but a low ridge west of Khattai runs down into the Son and there is exposed with an east-and-west strike and a thickness of 250 to 300 ft. It is underlaid by 30 ft. of greenish grey shales and overlaid by a similar rock. The lower shales gradually pass into the sandstone, of which over 50 ft. are exposed, the base of the series not being seen, though it is probable that these sandstones are part of the basement beds and not far removed from the junction with the older rocks.

On the north bank Mr. Vredenburg describes the section in the stream west of Hurma. Underlying the limestones of the Rhotas stage is a bed 30 ft. thick of hard sandstone, not unlike that of the

Kaimur series but somewhat more quartzitic. This rests on coal black splintery shales underlaid by limestones which have a local dip of 76° to N. 13° W., but becomes less lower down the section. The upper beds of this limestone resemble the Rohtas, but descending the section they pass into shales containing large black coloured calcareous concretions of the Kheinjua type. An almost continuous section of these shales, with occasional bands of impure sandstone, is seen till a band of limestone, about 40 ft. thick, is met with.

Limestone at Khattai.

This is the limestone regarded by Mr. Mallet as his No. 7, and from the wording of the memoir where it is said that "the outcrop recrosses the Son east of Hurma, at which village the limestone is seen, as mentioned at page 38[1]," it seems that he regarded this limestone as the one which is seen on the right bank of the Son west of Khattai. This was not Mr. Vredenburg's opinion, and having examined the section myself I can confirm his separation of the two limestones, of which that seen near Hurma belongs to a higher horizon than the other. There is consequently a gap in the section occupied by beds which are hidden by the Son, among which may be the continuation of the porcellanite stage.

East of Hurma, to the boundary of Rewah, the exposures of lower Vindhyan rocks are few and far between, the ground being deeply covered in a thick sheet of recent deposits; alluvial sands and gravels covered by a fine-grained loam of æolian origin. South of Deora some low hills of shales and ripple-marked sandstone are of typical Kheinjua type.

The boundary, as marked on the map, is largely conjectural. South of Naugi (Nowgai) the basement beds form a low hill composed of a conglomerate of small pebbles scattered through an earthy matrix. Southwards of Kosai (Kossai) the boundary can be traced, and on resurvey the difficulties of interpretation, referred to in the Vindhyan memoir,[2] of the section south of "Bergurrah"—Bargar of

[1] Mem., Geol. Surv. Ind., Vol. VII., p. 129.
[2] Mem., Geol. Surv. Ind., Vol. VII., p. 34.

the present map—were cleared up. It was found that the limestone was of transition age and formed a line of low hills diverging at a small angle from a similar line of hills formed by the basal conglomerate of the lower Vindhyans. South of Kosai these two lines of hills come together and there is one of which the western half is composed partly of limestone and partly of the sandstone of the lower Vindhyan basement beds. The eastern extremity of this hill is composed entirely of the sandstone and no limestone is seen to the east, its disappearance being due to its removal by denudation, previous to the deposition of the lower Vindhyans which overstep the eroded edges of the transition strata.

Basal limestone in Mirzapur.

After crossing the Rewah boundary into the Mirzapur district outcrops of a limestone band at the top of the basal stage begin to appear. This can be traced continuously to the exposure of limestone in the Son at Ghurdah. In the old survey this limestone was represented as No. 7 of the sequence established by Mr. Mallet further east, the later survey has established its true horizon and explained the origin of the mistake.

About Bargawan these transitions near their northern boundary contain a number of hard bands which, in the field, resemble those of the porcellanite stage and were taken for them. The limestone, being newer than these hard rocks, was naturally ascribed to the horizon No. 7. The more detailed survey lately made with the help of the accurate maps now available, showed that the true boundary of the lower Vindhyans lay further north than it had been drawn on the very imperfect maps used at the time of the original survey. A microscopical examination of the porcellanite beds in the transitions shows that they are of a cherty nature and show no indications of a volcanic origin.

At Ghurdah the lower Vindhyan outcrop is again reduced in width and no sign of the porcellanites is to be seen. Though no fault could be traced on this section, it is probable that these beds are here cut out by a strike fault, for they are well developed a short distance

to the east and continue from thence along the valley of the Son till they are finally hidden by the Gangetic alluvium.

Country east of Gurdah and Agori.

East of Gurdah the lower Vindhyan boundary trends southwards before resuming a generally east-and-west course. The scarp of the upper Vindhyans follows a similar course about 6 to 8 miles east of the lower Vindhyan boundary, exposing a large area of the rocks of this series between Kajrahat (Kujrahut), Agori (Agoree Khas), and Markundi (Murkoondee).

The lower boundary has been mapped by Mr. Vredenburg in detail on the accurate maps now available. He found the limestone of the basal stage everywhere well developed and overlying the basal conglomerates, except for a short distance in the valley of the Rer (Rehund) river where the limestone is in direct contact with the transition. Overlying the limestone come the beds of the porcellanite stage, which form a number of low hills about Beldaha (Bildeh) and Bauradih (Bowradeeh). To the east the ground is thickly covered with recent deposits, the only exposures west of the Ghaghar (Ghagar) being two small groups of low hills west of Markundi and north-east of Salkhan (Sulkhun), which will be referred to further on.

The porcellanites are again seen in the bed of the Son at Chopan and can be traced thence eastwards. East of Kota there are several exposures, by the roadside, of a conglomerate, similar to that seen north of Khaira, in which the pebbles are of a porcellanite like those found in this stage, imbedded in a matrix of similar type.

Limestone in the Ghaghar.

In the Ghaghar at Markundi there is an extensive exposure of blue limestone dipping east-north-east, and to the east of this numerous exposures of shales with large rounded black calcareous concretions, the typical rock of the upper Kheinjua stage, followed by bedded limestones of the Rohtas. The exposure of Rohtas beds is fairly continuous though much less than the normal thickness round the edge of the Kaimur sandstone, but west of the Markundi ghât (Aikpowah ghât) the upper

Vindhyans extend down into the low ground, and the older beds are covered by recent deposits.

Hills near Salkhan.

We may now return to a consideration of the low hills by Salkhan and Markundi. They are twice referred to in Mr. Mallet's memoir, once in the memoir itself (page 45), where the Salkhan hill is referred to as an inlier of the transitions. In the note appended to the memoir, and embodying the results of a later examination, this hill is referred (page 127) to the basement beds of the lower Vindhyans. Mr. Vredenburg, who visited these hills in the course of his survey of the lower stages in this neighbourhood, took the same view, basing his conclusion mainly on the presence of a glauconitic sandstone very similar to one found at some places among the basement beds.

Closely connected with the question of age of these sandstones is that of the limestone at Markundi, which was regarded by Mr. Mallet as the equivalent of his No. 7, by Mr. Medlicott and by Mr. Vredenburg as No. 2, or as the limestone of the basal stage. Mr. Mallet's ascription of this limestone to his No. 7 is with difficulty reconcilable with his reference of the Salkhan sandstones to his No. 1; on the other hand, the relation of the Markundi limestone to the nodular shales west of the Ghaghar is inconsistent with its reference to the basal stage, and it must be Mr. Mallet's No. 7 or some other limestone in the basal stage. This being so, it is difficult to account for the absence of the porcellanites anywhere round the Salkhan hills if these are formed of the basement beds, but all difficulty disappears if we regard them and the Markundi hills as formed by hard sandstone bands in the Kheinjua stage. The general dip along the axis of the open anticlinal, by which the boundary of the upper Vindhyans is thrown to the south, is very small, the Kheinjua outcrop should, consequently, have a great breadth in an east and west direction here; and if we had the lowest beds of the series brought up to the surface, there would be no room for their exposure, nor would it be easy to account for the absence of outcrops of the porcellanites without

invoking the aid of faults which cannot be traced in the main boundary of the lower Vindhyans.

Igneous intrusion.

This area is remarkable, as containing the only known case of intrusion of an igneous rock in the lower Vindhyans. In the stream-bed close to the village of Pataudh (Putwud), a dyke is exposed cutting the shales of the lower portion of the Kheinjua stage. Two others were seen on the track between Pataudh and Kanch (Kunuch). In each case the rock is very much weathered and has a soft ochreous and buff coloured weathered coating; with some trouble I was able, after breaking through this, to get some fragments of small cores of a comparatively unweathered grey rock, specific gravity 2·85, showing numerous small granules on the fractured surface. Under the microscope the rock consists of a ground mass of interlacing crystals, decomposed beyond possibility of recognition, while the granules are seen to be colourless almost spherical casts, lined with quartz crystals and not infrequently containing a few grains of an opaque mineral. Many of these, where they have been cut nearly through the centre, show a distinct approach to a hexagonal outline with rounded corners, resembling sections of leucite crystals. The rock appears to be, in fact, a much decomposed leucite rock.

The age of this intrusion cannot be fixed. It is certainly later than the outbursts which formed the ashes of the porcellanite stage, but how much later it is impossible to say.

Sandstone dykes.

In the limestone exposure at Markundi there are some curious dykes of sandstone, one of which is represented on Plate 2. They cut across the bedding, and ramify in a manner which simulates an igneous intrusion, but the rock which fills their veins is a sandstone composed of rounded grains of sand, cemented by a calcareous cement. In places this gives way to a limestone breccia, and fragments of limestone are not uncommon in the marginal part of the dykes. Similar dykes have been described by Darwin,[1] Diller,[2] Gresley,[3] and other observers, and

[1] Naturalist's Voyage round the world.

[2] J. S. Diller, Sandstone dikes. Bull. Geol. Soc. Am. I, 411—441 (1890).

[3] W. S. Gresley, Clay veins vertically intersecting coal measures. Bull. Geol. Soc. Am. II, 35-58 (1808).

have been attributed to injection from below, as the result of earthquakes, or as an infilling of crevices from above.

Mr. Diller showed, in the case of the dykes examined by him, that the sandstone must have been injected from below, not formed by infilling from above, and attributed this to earthquake action of the same kind which produces sand vents. Dr. Noetling in his memoir of the Yenangyoung oil field adopts a similar explanation for the shale dykes formed in that region.[4]

At Markundi I was unable to get any direct evidence bearing on the origin of these sandstone dykes. The occurrence of fragments of limestone lying with their longer axes more or less vertical suggests that they were detached and carried upwards by the sand, for if they had fallen from above into an open but partially filled fissure they would probably be found lying more or less flat, and with their longer axes at right angles to the edges of the dyke. There is also evidence to show that they are not due to recent filling of open fissures in the bending up of the bedding of the limestone against the sandstone of the dykes as seen in Plate 2. This bending is most naturally explicable on the supposition that it is due to a slight compression either at the time of injection or, more probably, after the induration of the sandstone. The occurrence of fragments of limestone shows that this had already solidified at the time of formation of the fissures now filled by the sandstone, and this combined with the evidence of their age makes it probable that, as in the American instances, the sandstone is truly intrusive in the limestone, and derived from a sand underlying the limestone.

Transition.

The transition rocks of this area are sufficiently treated in the chapter by Mr. Vredenburg. It will only be necessary to notice here the occurrence, described by Mr. Datta, of a curious conglomeratic rock about half a mile south-west of the termination of the Jungel outlier of the red shale series. The rock is described as a fine-grained laminated bluish shale, 5 or 6 ft. thick, through which small well-rounded pebbles are scattered. The rock is exposed on a hillside and cannot be traced, owing to the absence of exposures either eastwards or westwards.

[4] Mem., Geol. Surv. Ind., Vol. XXVII.

It was not possible to determine whether this peculiar rock belonged to those classed as transition or to the red shale series.

Red shale series.

The Jungel exposure of the red shale series has been examined by Mr. Datta and Mr. Vredenburg. It occupies a narrow closely folded synclinal whose axial plane hades to the south-south-east, and whose southern half shows inverted dips. The total length of the exposure is about 12 miles, and for 9 of these the upper quartzites form a conspicuous ridge or plateau, which is breached near its centre by the Parewar (Purawah) stream. The structure and mode of occurrence of this exposure will be understood from the cross-section, fig. 6.

In this exposure Mr. Vredenburg considered that the series should be divided into two divisions only. The upper of these is constituted by the upper stage of sandstones, while the middle and lower stages are grouped together and regarded as representative of each other; the shales, when present, occurring above the sandstones. The lower sandstone and conglomerate is variable in thickness, the upper part being sometimes replaced by shale, while at other places the arenaceous beds spread upwards and replace the shales. Occasionally, as at Titihadar, a considerable thickness of shale is underlaid by an important conglomerate; here it is probable that there is a greater development of the lower stages, owing to a depression in the original floor of deposition.

The lowest beds are, as usual, conglomeratic, and vary much in thickness. The conglomerates attain their maximum thickness at Titihadar, where they form high precipitous hills which stand up like gigantic walls, the artificial appearance being enhanced by the large and irregular-shaped fragments of which the conglomerate is composed.

East of the Parewar stream this conglomerate maintains its importance for more than two miles, forming an irregularly serrated ridge. The conglomerate then decreases in thickness and the ridge sinks to the level of the plain, only occasionally rising above the level of the recent deposits. It becomes more important towards Jungel, but con-

tains numerous shaly bands. At the eastern extremity it is coarsely conglomeratic.

West of the Parewar river the basal conglomerate after rapidly diminishing in thickness disappears, and shales are in direct contact with the underlying transitions. Further west the conglomerate re-appears and is seen at the western extremity of the outcrop.

Along the southern border the conglomerates are found in variable thickness, where not covered by recent deposits, but nowhere attain the thickness or conspicuousness exhibited at Titihadar.

The pebbles in the conglomerate are usually well rounded, often of large size. They consist of vein quartz, red jasper, and various kinds of sandstone, some of which are themselves conglomeratic and contain Bijawar fragments.

The shales are of the usual type, but more slaty than is often the case and show greater signs of compression than those near Ghurder. They are usually purple and always very siliceous, passing readily into an impure sandstone. Under the microscope they are seen to consist mainly of quartz and mica, coloured by an admixture of oxide of iron. They are more gritty and generally less developed on the south side of the syncline and for a short distance, near the southern boundary south-west of Jungel, are wanting; this may, however, be due to a small fault cutting them out.

The thickness of the two bottom stages combined is from 300 to 500 feet, but they show great individual variations owing to the manner in which the one type of deposit is horizontally replaced by the other.

The sandstone of the upper stage is of moderately fine grain, with occasionally scattered pebbles. Under the microscope the grains of sand are seen to be well rounded, but they have all been enlarged by secondary outgrowths of quartz. Some of the grains are aggregates of smaller grains, indicating their derivation from some older sandstone. The quartz is traversed by numerous lines of fluid inclusions, which must have been formed, in part at least, subsequent to the consolidation of the rock, as they run through the second-

ary extensions of the original grains and even across several of these.

In thickness these sandstones attain fully 1,000 feet; they not only occupy the greater part of the area of the outcrop, but also its most conspicuous feature, rising into a bold plateau, whose steep sides and deep gorges form a great contrast to the lower, more irregular, and scattered hills of the surrounding transitions.

CHAPTER XI.—ECONOMIC GEOLOGY.

(R. D. OLDHAM.)

Iron.

There is an almost complete absence of minerals of economic value in the region under description. The only mineral industry in actual operation is that of iron manufacture. This is manufactured from hæmatite or limonite in several villages in Rewah territory, the iron being utilized locally in the manufacture of axes and agricultural implements. The industry is evidently much smaller than in former days when there must have been a considerable export of iron to supply the needs of the population in the Gangetic plains, and great heaps of iron slag are commonly met with in the Son valley and in the northern part of the transition area. The manufacture as carried on in Rewah State presents no peculiarities worthy of notice.

Copper.

Copper was formerly worked at one place about 1½ miles north-east of Cherka, the old mine being locally known as "Surak Khodawn." The old incline, by which the mine was entered, is still open at the surface, descending at an angle of about 15°. The rocks exposed are dark, mostly purple or violet coloured micaceous slate, passing into black-coloured rock. They stand vertical with a general strike to N. 35 E. Right in the centre of the roof of the incline the beds are crushed and there is less than a foot of very ferruginous stuff, apparently the gossan of the lode, which, as well as the slates on either side, show occasional green patches, due to copper staining. I was not able to enter the incline owing to the overpowering stench produced by the dung of the innumerable bats which use the tunnel as a refuge during the day, and no special attempt to penetrate along it was made as barely 20 feet from the entrance, as measured along the surface, begins a long hollow caused by the falling in of the old mine. This hollow extends for a couple of hundred feet along the strike of the rock, is about 15 feet deep, and three times that in width; on either side the rock stands up showing the bare vertical bedding planes, stained

here and there with copper. From the size of the depression formed by the falling in of this mine, the vein must have been followed and worked to a considerable depth, but no record or even tradition of the working of the mine remains.

On Captain Sherwill's geological map of Bengal,[1] copper is marked in a position which should be near Fagwa. Mr. P. N. Bose reports that there are some old diggings near this village ; at one place a vein in quartzite, parallel to the strike, seemed to have been worked for a distance of about 50 yards. Mr. Bose, however, reports that he saw no trace of copper in the rocks and can give no indication of the object of these workings. Captain Sherwill's note on his map, which is a mere skeleton one, more probably refers to the copper working near Cherka, unless indeed it was founded on a baseless rumour.

On the same map copper is marked south of Bardi, but nothing was seen or heard of any copper workings in this neighbourhood.

Lead.

Galena occurs in small quantities in the limestones of the Rohtas stage, but does not seem to have ever been worked. The quantity, in all the cases where any has been seen, is far too small for this, as it only occurs in minute strings and isolated crystals.

An old lead mine near the village of Urgarhi, in the gneiss area, was prospected in 1892-93 by Mr. R. A. D. Sewell, and a vein of galena and quartz some 9 inches thick was found at a depth of 30 feet from the surface. The galena on assay yielded 61·6 per cent. of lead and 7 oz. 16 dwt. 14 gr. silver to the ton of lead.[2]

[1] Geological map of the Northern Front of the Vindhya Hills, extending from Allahabad to Rajamahal, showing the position of all the known Coal Beds of that tract, and also of the Silver, Copper, Lead and Antimony localities as well as the Principal Iron Measures. Surveyed and constructed by Captain Walter S. Sherwill, 66th Regiment, Native Infantry, Revenue Surveyor, in 1842 to 1851.

[2] The specimens referred to in Dr. Ball's Volume of the Manual of the Geology of India (Vol. III, Economic Geology, p. 248) as coming from "near the village of Burgowa, 10 miles south of Burdi pargana." The mine is five miles north-west of Bargawa, the head-quarters of one of the principal Thakurs of this part, and is in the southern part of the Bardi pargana.

Lime and building stones of excellent quality are found in great abundance in the rocks of the Vindhyan system, but are worthless owing to the expense of transport and the absence of a local demand.

GEOGRAPHICAL INDEX TO PLACES MENTIONED IN THE PRECEDING MEMOIR.

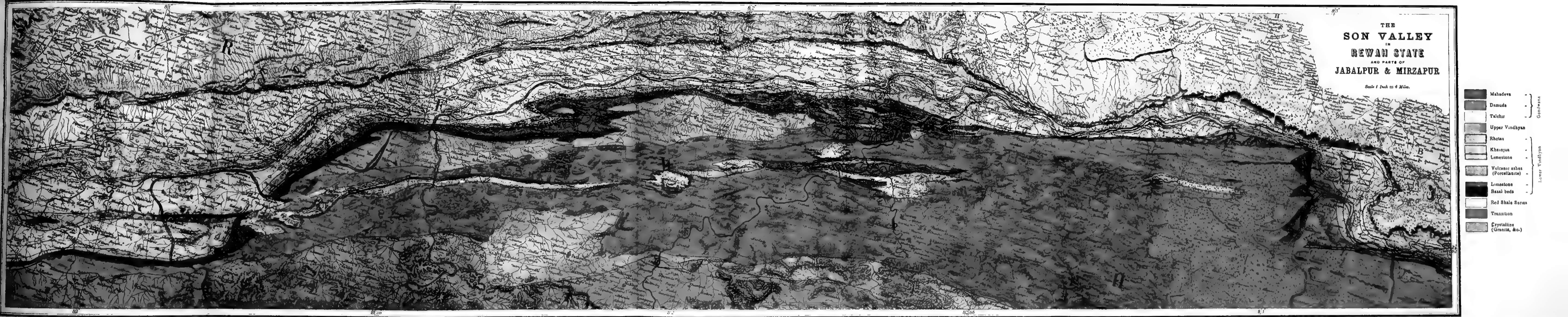
Latitudes and longitudes are given to the nearest minute and taken from the standard sheets on scale 1″=1 mile. The longitudes on the map accompanying this memoir, which are taken from the sheets of the Atlas of India, will sometimes be a minute further east than that given in the Index :—

Place	Latitude	Longitude
Agori	24° 33′	82° 30′
Amlai	24° 17′	81° 25′
Bagháia	24° 24′	82° 45′
Baghar	24° 17′	81° 28′
Bagháwa	24° 29′	81° 50′
Bagra	24° 24′	82° 45′
Baheria	24° 01′	81° 05′
Baikona	24° 07′	81° 14′
Bakáili	24° 09′	81° 16′
Bakura	24° 15′	81° 24′
Bannái	24° 22′	82° 29′
Bardela	24° 18′	81° 29′
Bardi	24° 32′	82° 25′
Bargama	24° 29′	81° 54′
Bárgar	24° 34′	82° 45′
Bargáwa	24° 12′	82° 26′
Bargáwan	24° 36′	82° 57′
Barhat	24° 31′	82° 27′
Barhata	24° 04′	81° 14′
Barhatola	24° 05′	81° 20′
Bártona	24° 13′	81° 21′
Batrani	24° 20′	82° 02′
Bauradih	24° 34′	83° 04′
Bela	24° 13′	81° 20′
Beláwa	24° 26′	82° 33′
Beldaha	24° 35′	83° 03′
Bhaghor	24° 33′	82° 21′
Bhanni	24° 07′	81° 26′
Bharra	24° 23′	82° 15′
Bhelki	24° 26′	81° 49′
Bhitari	24° 27′	81° 52′
Bhomráha	24° 07′	81° 24′
Bichiadol	24° 11′	82° 09′
Bijaigarh	24° 34′	83° 14′
Boorgaona	24° 19′	81° 24′
Chakari	24° 28′	82° 30′
Chatni	24° 27′	82° 34′
Cherka	24° 04′	81° 21′
Cheropahár	24° 27′	82° 33′

Place	Latitude	Longitude
Chilari	24° 27′	81° 50′
Chingo	24° 16′	82° 35′
Chopan	24° 31′	83° 04′
Churhat	24° 25′	81° 42′
Dádri	24° 24′	82° 11′
Dangarha	24° 17′	81° 19′
Dánri	24° 21′	82° 03′
Daoraha	24° 19′	81° 24′
Dembha	24° 17′	81° 29′
Deora	24° 10′	81° 15′
Deora	24° 11′	82° 22′
Deora	24° 29′	82° 38′
Deori	24° 09′	81° 29′
Deori	24° 13′	81° 04′
Deori	24° 25′	82° 31′
Deosar	24° 12′	82° 19′
Dholki	24° 31′	82° 51′
Diholi	24° 30′	81° 53′
Devalond	24° 12′	81° 20′
Dol	24° 23′	82° 13′
Dowára	24° 26′	81° 46′
Duári	24° 22′	81° 34′
Dubhiabár	24° 05′	81° 18′
Dueria	24° 07′	81° 04′
Gángi	24° 32′	82° 32′
Garhara	24° 17′	81° 25′
Ghara	24° 08′	81° 26′
Ghidaora	24° 21′	81° 35′
Ghungta	24° 19′	81° 32′
Ghurder	24° 23′	82° 21′
Ghusra	24° 07′	81° 15′
Gidela	24° 15′	81° 12′
Ginaor	24° 27′	81° 42′
Girwi	24° 27′	82° 38′
Gurdah	24° 36′	83° 00′
Gursari	24° 13′	81° 05′
Hardi	23° 58′	81° 09′
Harphari	24° 26′	82° 24′
Hinaoti	24° 18′	81° 20′
Hinaoti	24° 33′	82° 13′
Hurma	24° 33′	82° 34′
Jagráowa	24° 26′	82° 35′
Jarkarua	24° 30′	82° 52′
Jhala	24° 21′	81° 35′
Jhinna	24° 13′	81° 18′
Jhokho	24° 26′	82° 16′
Jholukhor	24° 22′	82° 09′
Jungel	24° 31′	82° 54′
Kachinar	24° 11′	82° 02′
Kachra	24° 09′	82° 01′
Kaitháha	24° 21′	81° 21′
Kajrahat	24° 27′	83° 06′

N

Place	Latitude	Longitude
Páwa	24° 27′	81° 48′
Piparwani	24° 28′	82° 32′
Piperadol	24° 13′	82° 18′
Pokhra	24° 22′	82° 08′
Ponri	24° 08′	82° 01′
Pori	24° 22′	81° 45′
Ragwar	24° 22′	82° 14′
Raidooria	24° 17′	81° 25′
Raikhor	24° 21′	81° 32′
Rámgarh	23° 58′	81° 07′
Rámnagar	24° 12′	81° 12′
Rámpur	24° 20′	81° 31′
Rehi	24° 24′	82° 15′
Reiwas	24° 25′	81° 34′
Rimar	24° 12′	81° 20′
Rudauli	24° 34′	83° 09′
Saháol	24° 33′	82° 17′
Salkhan	24° 35′	83° 05′
Samaria	24° 22′	81° 46′
Saria	24° 12′	81° 21′
Sarsi	24° 04′	81° 04′
Sáru	24° 22′	82° 05′
Sejáre	24° 08′	81° 23′
Sendhwa	24° 13′	81° 37′
Sendura	24° 16′	81° 52′
Sháhargar	24° 09′	81° 20′
Sidi	24° 23′	81° 55′
Silpi	24° 36′	82° 50′
Sirwa	24° 28′	82° 31′
Sisla dán	24° 28′	82° 35′
Sitkuri	24° 10′	81° 18′
Sukwari	24° 05′	81° 02′
Sulkma	24° 07′	81° 01′
Sureyha	24° 04′	81° 43′
Susnái	24° 28′	83° 13′
Tagwa	24° 17′	82° 00′
Tál	24° 11′	82° 01′
Tarka	24° 24′	82° 11′
Tikat	24° 28′	81° 46′
Tikhwa	24° 01′	81° 16′
Titihadár	24° 31′	82° 47′
Ucheyra	24° 14′	81° 18′
Urangi	24° 30′	82° 31′
Urgarhi	24° 14′	82° 26′


THE
SON VALLEY
IN
REWAH STATE
AND PARTS OF
JABALPUR & MIRZAPUR
Scale 1 Inch = 4 Miles.
Mahadeva
Damuda
Talchir
Gondwana
Upper Vindhyan
Rhotas
Khenjua
Limestone
Volcanic ashes (Porcellanite)
Limestone
Basal beds
Lower Vindhyan
Red Shale Series
Transition
Crystalline (Granite, &c.)

WIND-GAP THROUGH THE RIDGE OF PORCELLANITES, EAST OF POKHRU.

SANDSTONE DYKE IN LIMESTONE, MARKUNDI.

NDIA

PEA

Drawing by E. Vredenburg.

Lith., Geol. Surv. of India Office

VIEW FROM THE GHURDER PEAK

LOOKING NORTHWARDS.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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GEOLOGICAL SURVEY OF INDIA.

VOL. XXXI, PART 2.

A GEOLOGICAL SKETCH OF THE BALUCHISTAN DESERT, AND PART OF EASTERN PERSIA, *by* E. VREDENBURG, B.L., B.SC. (PARIS), A.R.C.S.

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THE VOLCANO KÓH-I-TAFTÁN IN EASTERN PERSIA.

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PART I.

GENERAL.

CHAPTER I.—INTRODUCTION—PREVIOUS OBSERVERS.

Road followed by the party.

During the cold season of 1898 to 1899, I had an opportunity of geologically examining a portion of the north-western territories of Balúchistán and some of the adjoining districts of Eastern Persia. I accompanied the Political Assistant of Chagai during his usual cold weather tour, and, as I was more or less tied down to his line of march, I did not enjoy much facility for examining the geology of the district. Most of this region is a desert of stones bounded to the north and south by hill ranges; the "Seistán road" which we followed from Nushki to Malik-i-Siáh Kóh (or Kóh-i-Malik-Siáh), is a mere camel track running across the desert plain. The track usually lies at a great distance from the hills, and throughout the plain all the older rocks are concealed beneath sand dunes and recent agglomerates. Accordingly, I reached the Persian frontier having had nothing but

the most meagre opportunities for geological observation, with the exception of a short visit to the volcanic mountain Kóh-i-Sultán. On the 19th of January I reached Malik-i-Siáh-Kóh where stands the boundary pillar that marks the triple limit of Afghánistán, Balúchistán and Persia. From Malik-i-Siáh-Kóh we parted with the Political Assistant and travelled up to Mirjawa through the Persian province of Sarhad. Here we again met the Political Assistant. After a very short visit to the active volcano Kóh-i-Tafdán I parted definitely with him and travelled back from Mirjawa to Nuskhi either alone or in company with Mr. G. P. Tate of the Trigonometrical Survey. I was able this time to remain one week in the Kóh-i-Sultán and examine a number of other ranges; unfortunately the season was by this time far advanced and I was not able to spare the time necessary for unravelling many interesting problems.

It is a duty and pleasure for me to express my best thanks to Mr. Tate to whose kindness, and knowledge and experience I am indebted for much help and assistance throughout the journey.

Previous observers.

Confining both on Persia and Balúchistán, and including as it does some of the most inhospitable portions of either country, this region has been seldom visited. Explorers of Balúchistán have seldom proceeded so far west, while the numerous scientific expeditions in Persia have not generally reached so far east. Travellers proceeding by land from India to Persia or *vice versá* usually avoid the desert as far as possible and traverse the more populous districts to the north or to the south. The few descriptions that have been published are either works of general interest, or else deal with questions of physical geography rather than purely geological enquiry.

The earliest explorer of Persian Balúchistán in the present century was Captain Grant who visited the country in 1809. But his route lies entirely west of the regions described in the present Memoir.[1]

[1] Journal of a Route through the Western Parts of Mekrán, by Captain N. P. Grant. Journ. Roy. As. Soc., Vol. V (1839), pp. 328-342.

Pottinger and Christie (1810).

In 1810, Pottinger traversed the desert of Balúchistán from Nushki to Bampúr, the road followed by him lying mostly at some distance to the south of the region which I visited. He has recorded some interesting observations on the district in his "Travels in Baloochistan and Sinde" (London, 1816), which also contains some extracts from the diary of Captain Christie who travelled from Nushki to the Helmand and thence to Seistán.

Háji Abdúl Nabi (1838-39).

There is some useful information in the journal of Háji Abdúl Nabi of Kábul who travelled in Balúchistán during the years 1838-39.[1] But his observations refer almost entirely to districts south of those which I visited.

Conolly, 1839.

On the other hand, the journey accomplished by Captain Edward Conolly and Sergeant Cameron was through districts lying further north. In his "Sketch of the Physical geography of Seistan"[2], Captain Conolly gives an interesting description of that province which I was unfortunately prevented from visiting although I travelled up to its boundary.

Seistán was also visited by Leech in 1840,[3] Ferrier in 1845,[4] and Khanikoff in 1858.[5]

Cook, 1861.

Dr. Cook's "Topographical and geological sketch of the province of Sarawán, or northern portion of the tableland of Beloochistan"[6] is concerned directly with geology, but refers to a district situated east of the one which I studied.

[1] Notes taken on a tour through parts of Baloochistan, in 1838 and 1839, by Hajee Abdun Nabee of Kabul. Journ. As. Soc. of Ben., Vol. XIII (1844), pp. 667-706 and 786-826.

[2] Journ. As. Soc. of Ben., Vol. IX (1840), pp. 710-726.

[3] "A Description of the Country of Seisthan," by Lieutenant R. Leech. Journ. As. Soc. of Ben., Vol. XIII (1844), pp. 115-120.

[4] "Caravan Journeys and Wanderings in Persia, Afghanistan, Turkistan and Beloochistan," by J. P. Ferrier. London, John Murray, 1856.

[5] "Memoire sur la Partie Méridionale de l'Asie Centrale," par Nicolas de Khanikoff. Paris, 1862.

[6] Transactions of the Medical and Physical Society of Bombay, No. VI, New Series (pp. 1-44).

The boundary commissions of 1870-72 which defined the eastern frontier of the Persian Empire in the Mekrán and in Seistán afforded ample opportunity for the study of those districts till then so seldom visited. The results of these investigations have been recorded in the first volume of "Eastern Persia," and in various contributions to scientific publications.[1]

W. T. Blanford, 1872.

In 1872, Dr. Blanford accompanied by Sir O. St. John accomplished a journey the results of which both zoological and geological are given in the second volume of "Eastern Persia".[2] Although the districts examined by Dr. Blanford lie west of those upon which I am reporting, yet this is the most important contribution bearing directly upon the geology of the region. Upon perusal of this work, anyone who has travelled in the desert of Balúchistán cannot but be struck by the evident similarity of the adjoining Persian provinces. In fact, from a geographical as well as a geological point of view, the two evidently belong to one region. Amongst the points which particularly invite attention are the almost exclusive predominance of upper cretaceous and lower tertiary strata, the volcanic rocks of the same age associated with them, the high angles of dip and considerable amount of disturbance of these rocks.[3] The recent deposits, the gravel terraces, the various features of the physical geography are quite similar to what is seen further east. Many details of great interest are given respecting the recent and sub-recent cones of the

[1] Eastern Persia, an account of the Journeys of the Persian Boundary Commission, 1870-71-72. Vol. I. The Geography with narratives by Majors St. John, Lovett, and Ewan Smith and an Introduction by Major-General Sir F. J. Goldsmid, C.B., K.C.S.I. London, Macmillan and Co., 1876.

"Journey from Bandar Abbas to Mash-had by Sistan, with some account of the last-named Province," by Major-General Sir F. J. Goldsmid. Journal of the Royal Geographical Society, Vol. XLIII (1873), pp. 65-83.

"Narrative of a Visit to the Kuh-i-Khwajah in Sistan," by Major B. Lovett. *Ib.* Vol. XLIV (1874), pp. 145-152.

[2] "Eastern Persia. Vol II, the Zoology and Geology," by W. T. Blanford (London, 1876).

[3] *Ib.* p. 461.

western portion of the volcanic district to which belong in an easterly direction the Kóh-i-Tafdán and Kóh-i-Sultán described in the present Memoir.

Dr. Bellew, 1872.

Dr. Bellew who accompanied General Pollock's mission to Seistán in 1872 has written some interesting descriptions of that province.[1]

The physical geography of the same region has also been discussed by Sir H. O. Rawlinson in his "Notes on Seistan."[2]

MacGregor, 1877.

A few details of scientific interest are given incidentally in General MacGregor's "Wanderings in Balochistan" (London, Allen and Co., 1882) in which he describes a journey performed in the company of Captain Lockwood during the year 1877. The route which they followed largely coincided with the one travelled over by me.

C. L. Griesbach, 1884.

The members of the Afghán boundary commission of 1884-85-86 marched first from Quetta to Nushki; but beyond this point the route they followed ran north of the one which I visited. The geological features of the road from Quetta to Nushki, and in the neighbourhood of the latter place, have been described by Mr. Griesbach in the Records of the Geological Survey.[3]

In Lord Curzon's "Persia and the Persian Question" (London, 1892) a very useful résumé is given of the knowledge gathered up to the date of publication of the book, concerning the eastern districts of the Persian Empire.[4]

Brazier-Creagh and Sykes, 1893-94.

In 1893-94, Colonel Sykes and Major Brazier-Creagh performed a journey through Eastern Persia from Cháhbar on the Mekrán Coast up to the region immediately adjoining the one dealt with in the present Memoir in the

[1] "Record of the March of the Mission to Seistán under the command of Major General F.R. Pollock, C.S.I.," by Surgeon H. W. Bellew (Calcutta, 1873).
"From the Indus to the Tigris" (London, 1874).

[2] Journ. Royal Geographical Society, Vol. XLIII (1873), pp. 272-294.

[3] "Afghán Field-notes," by C. L. Griesbach. Rec. Geol. Surv. Ind., Vol. XVIII (1885), pp. 57-64.

[4] Vol. I, pp. 223-244; Vol. II, pp. 237-267.

Persian province of Sarhád. Major Brazier-Creagh collected, amongst the recent volcanoes, a very interesting series of specimens which were examined at the Office of the Geological Survey of India and described in the Records.[1] An account of the journey is given by Colonel Sykes in his "Recent Journeys in Persia".[2]

Our geographical knowledge of these regions was completed by the Afghán-Balúch boundary commission of 1894-96, and the Perso-Balúch boundary commission of 1896.[3]

I travelled through several of the localities visited by the members of these commissions, which has enabled me to complete some of the geological data connected with the mode of occurrence of the specimens which they collected. The route followed by the Afghán-Balúch boundary commission in 1896 coincided in several places with my own line of march; and in that year, two series of specimens were collected respectively by Dr. F. P. Maynard and Captain A. H. McMahon. The former collection was described by Mr. Holland in a paper read before the Asiatic Society of Bengal in December 1896, and published in the Records of the Geological Survey of India.[4] The second collection was examined by General McMahon who read a description of the specimens before the Geological Society of London in March 1897.[5]

Dr. Maynard, Capt. McMahon, 1896.

T. H. Holland, 1896.

General McMahon, 1897.

[1] Rec. Geol. Surv. Ind., Vol. XXX (1897), pp. 253-254.

[2] Geographical Journal, Vol. X (1897), pp. 569-597.

[3] "The Southern Borderlands of Afghanistan," by Captain A. H. McMahon, C.I.E. Geographical Journal, Vol. IX (1897), pp. 393-415.

"The Perso-Beluch Boundary," by Colonel T. H. Holdich, R.E. *Ib.* pp. 416 422.

[4] "An account of the Geological specimens collected by the Afghán-Balúch Boundary Commission of 1896," by Thomas H. Holland. Rec. Geol. Surv. Ind., Vol. XXX (1897), pp. 125-129.

[5] "Notes on some Volcanic and other Rocks, which occur near the Baluchistan Afghan Frontier, between Chaman and Persia," by Lieut-Genl. G. A. McMahon, V.P.G.S., and Capt. A. H. McMahon, C.I.E., F.G.S. Quart. Journ. Geol. Soc., Vol. LIII (1897), pp. 289-309.

CHAPTER II.—PHYSICAL FEATURES.

SECTION I.—GENERAL CHARACTERS.

Geographical situation.

The country examined is included within the parallels 28°30′ and 30°N., and the meridians 60°30′ and 66°E. It may be roughly divided into two regions, each possessing a different type of structure. The northern part is mostly a great desert plain with a few groups of hills irregularly scattered about it, and extends northwards as far as the Helmand river and even beyond. To the south-east, south and south-west, this comparatively low-lying area is bounded by ranges of mountains in parallel or rather concentric ridges forming roughly an arc of a circle. To the extreme east and extreme west of the region visited, at Nushki and at Kóh-i-Malik-Siáh, where the ranges strike respectively north-east and north-west, the mountains form very close-set parallel ridges. But in the interval between these two extreme points, the inner ranges, that is those bordering on the great desert, become gradually separated from one another by broad plains, mostly desert areas strewn with black pebbles, when not invaded already by the sand dunes.

Two types of structure.

Throughout the region characterized by parallel ranges, the rocks are nearly everywhere highly folded, with a considerable development of slaty cleavage. The hills which rise in isolated groups from the midst of the great desert plain, on the other hand, exhibit only moderate flexures without any predominating direction of strike, or the rocks constituting them may even be quite horizontal. The broad plains above mentioned as occurring between the parallel ranges partake of the nature of the great desert depression; both must be regarded as regions of minimum disturbance, and they are moreover, in many cases, real areas of subsidence. This is well shown by the structure of the mountains in their neighbourhood; they exhibit in a marked degree

the "scaly structure" which has been often described in the case of the Alps and Himalayas, and there are numerous examples of thrust-planes and overfolds, the thrust being always towards the low-lying area, whether that be north or south of the mountains.

Rocks occurring in either type of region are not different.

The contrast which exists between the structure of the parallel ranges and that of the low-lying districts finds no correspondence in any difference of the rocks constituting them. In either type of country, exactly the same strata were observed: they are shales, sandstones, and limestones, often containing an enormous proportion of volcanic material, and ranging in age from upper cretaceous to upper eocene. In a great many instances the rocks are nearly or quite unfossiliferous, but where fossils can be identified the above are respectively the oldest and newest horizons.

In most cases the volcanic strata appear to be especially abundant amongst the upper cretaceous and earliest tertiary beds, but ash-beds still occur amongst strata which their fauna shows to be of the age of the "Ranikot" of Sind, and in one instance, at Saindak, strata containing a typical "Khirthar" fauna rest, apparently with perfect conformity upon a thick bed of volcanic conglomerate.

In addition to these stratified rocks, both volcanic and sedimentary, there are great igneous intrusions which are of eocene age at the oldest, as they are found to cut through all the marine strata above mentioned. They consist of granites, syenites, and diorites, with some more basic dykes.

Siwaliks.

Apart from the recent and sub-recent gravels, which naturally occur only in the valleys and plains, the only rocks that are restricted to particular regions are the Siwaliks: these occur along the margin of the desert plains in the neighbourhood of the tall ranges of older rocks. As in the case of the Himalayas, they usually dip towards the range which they fringe, the dip being, therefore, southerly, where they occur along the southern edge of a plain; it is not always northerly as in the case of the Himalayas.

SECTION 2.—HYDROGRAPHY.

All this region is an area of closed drainage, and, as is usual in regions where the rainfall is of the scantiest, the hydrographic basins are very irregularly and vaguely defined. Very little water ever reaches the great lake basins or "hamuns," most of which are now barren plains of sun-cracked alluvium. The absence of rain has not allowed the formation of any well-marked river-course possessing an individuality of its own. Where the mountain ranges overlook the desert plain, innumerable dry channels follow the slopes parallel to one another. They never contain any water except for a few hours at a time in the rare event of a shower of rain; not one of them contains a stream running even for part of a season, such as would excavate its bed more deeply and gradually draw towards it as tributaries the supply of the neighbouring channels. Each of these furrows runs from the hill into the plain, following an almost straight course absolutely independently from its neighbours. I have observed instances in which two such channels excavated to widely different depths approach so close to one another for a certain part of their course, that they are separated by nothing but a mere ridge. Yet even the shallower of the two is excavated sufficiently deep to show that it has already existed for a lengthy period along the same course which it now occupies. In a country favoured by a normal and regularly distributed amount of rainfall, the ravine flowing at a higher level would have been diverted from its course to become a tributary of the adjacent deeper channel long before it had become so deeply intrenched within its own banks. After a course of five or six miles, or often much less, these parallel ravines become completely obliterated in the great desert plain. The topography thus produced is most typically represented on map 89, north of Nushki.

Where the ranges are perhaps favoured with a little more rainfall, instead of being merely furrowed along their slopes by the channels above described, they are cut through at intervals by deeper channels which occasionally form narrow gorges or rifts locally called

"tangi;" a physical feature which is specially exaggerated where the river bed traverses a calcareous band or some other hard rock, such as an intrusion of diorite. This channel may represent the outlet of a comparatively large drainage area within the hilly region, but on reaching the plain its fate is no better than that of the small furrows just mentioned: no sooner has it broken through the last ridge of the mountains than it separates at once into a many-branched delta, forming a broad and shallow cone of dejection or "alluvial fan."

Talus or "daman."

The talus of conglomerate skirting the hill ranges, and formed either by the deposits of the numerous parallel channels, or by the coalescence of a series of "fans," takes the shape of a broad inclined plane which is termed the "daman," that is the "skirt" of the mountain. Owing to the absence of any powerful drainage, these deposits attain a considerable size, and the "daman" reaches proportions almost comparable to those of the mountain whose *débris* have formed it, reaching higher and higher upon its slopes. The gradient of these taluses is so low that the eye hardly realizes the great height which they reach up the mountain slopes, and this explains the dwarfed appearance of many of the hill ranges notwithstanding their considerable altitude.

This great compound talus or "daman," formed as it is by a number of overlapping taluses and cones of dejection, is extremely variable in its composition, coarse conglomerates and finer deposits alternating in a very irregular manner. Some of the coarser deposits are eminently permeable and the water supplied by the scanty rainfall, instead of being able to remove this gigantic deposit, becomes stored within its mass. It is then protected against evaporation, and this explains the important part played by these talus deposits in the economy of the district. From this natural reservoir is drawn the supply of water which flows along the artificial underground channels called "káréz" in Balúchistán and "kanát" in Persia, or which, of late years, has been obtained with less labour by the boring of artesian wells, allowing many a fair oasis to flourish in places that would be otherwise nothing but desert. The question

has been dealt with very fully by Mr. Oldham in the Records of the Geological Survey.[1]

Stony desert or "dasht."

Occasionally an unusually heavy shower will cause a flood, carrying many of the boulders into the plain below. These floods, which, no doubt, were more frequent in former times, have spread the pebbles over large areas in the desert, giving rise to the stony plains known by the name of "dasht." The outer surface of nearly all the pebbles is coloured black through the oxidation of iron compounds; and this dark tinge still further increases the desolate appearance of these dreary plains, which occupy immense areas not only in Balúchistán, but throughout Persia. In the latter country they have formed the subject of a special study by Mr. Blanford.[2]

Even in places where, not infrequently to this day, after an unusually heavy shower, large bodies of water do reach the plain without sinking into the ground or being evaporated, the water does not gather sufficient strength to give rise to a definite channel, except in a very few cases where a stream whose head-waters drain a considerable mountain region has preserved sufficient importance to excavate a channel through the plain. Such exceptional cases are those of the Lora which drains a large area of high ground in the neighbourhood of Quetta and whose course can be followed up to the great dried-up lake called after its name the "Lora Hamun." Such is the Mashkhel river which gives its name to another shallow lake-basin, the "Hamun-i-Mashkhel." Such, again, is the Tahlab river whose course forms the boundary between Persia and Balúchistán. But in most cases the water is ponded back by irregularities of the ground and spreads into shallow pools which may cover a large area, but become dried up in a few days, sometimes

[1] "Sub-recent and Recent Deposits of the Valley Plains of Quetta, Pishin, and the Dasht-i-Bedaolat; with appendices on the Chamans of Quetta; and the Artesian water-supply of Quetta and Pishin," by R. D. Oldham. Rec. Geol. Surv. Ind., Vol. XXV (1892), pp. 36-53.

[2] "On the Nature and Probable Origin of the Superficial Deposits in the Valleys and Deserts of Central Persia," by W. T. Blanford. Quart. Journ. Geol. Soc., Vol. XXIX (1873), pp. 493-503.

in a few hours, leaving a fine deposit of light-coloured mud, which gradually accumulates, forming plains called "pat." Some of these "pats," where water is available from a káréz, have been locally cultivated, but as a rule they constitute the most barren portions of the desert without any of the bushes that occur at intervals in the stony plains, or even occasionally take root amongst the sand dunes.

Plains of fine alluvium or "pat."

These "pats," often half-concealed by the ever-encroaching sand dunes, pass imperceptibly into the stony "dasht," and possess usually very ill-defined limits. Where, however, they become of considerable size, and where they are fed by streams that can give rise to more or less permanent sheets of water, they exhibit a more distinct line of shore, and gradually merge into the class of shallow lakes called "hamun." The Lora Hamun, which is now absolutely dried up, is nothing more than a gigantic "pat." The Hamun-i-Mashkhel, dry for the greatest part, still contains water in two depressions, now separate, but which some of the oldest inhabitants of the district remember having seen once united.[1] The Gaud-i-Zirreh is described by Captain McMahon as "a lake of salt brine fringed by an ever-encroaching margin of solid salt."[2]

Lake basins or "hamun."

It may be mentioned here that these three lacustrine depressions lie at very different altitudes. The Lora Hamun is at an altitude considerably higher than the two others, and yet appears to be perfectly independent from them.[3] Moreover, the drainage areas

[1] Information kindly communicated by Captain Roome.

[2] Quart. Journ. Geol. Soc., Vol. 53, p. 291.

[3] The depression in which are collected the waters of the Helmand basin affords an instructive illustration of the uncertain manner in which hydrographic basins are defined in a desert region. The waters of the Helmand and of several rivers flow into two shallow freshwater lakes surrounded by a reedy swamp. Sometimes the lakes overflow into this marsh and thus become united. The fertile plain of Seistán proper is but the delta of the Helmand, and has been formed partly by the sediments carried by that river into a lake which formerly occupied the entire depression, and partly owing to the dessication of the lake itself. The "hamuns" and marshes that still exist are separated in ordinary season by a low watershed from the southern and lowest part of the depression, which contains the Zirreh lake. Thus, in ordinary seasons the Gaud-i-Zirreh is the centre of a basin absolutely

of these important depressions are by no means coterminous, but are separated by a number of minor independent depressions. Occasionally one of these may be unusually deep, and owing to some exceptionally favourable water-supply may allow the formation of a perennial sheet of water. These small ponds are called "nawar." They usually are surrounded by a cultivated oasis and supply water to the nomads and their flocks often to great distances. Shady tamarisks, many centuries old, grow by their banks, and the women who come to fill their "mashks" with water, the sheep, cattle, and camels which in countless flocks come to quench their thirst, form a busy scene which affords a strange contrast to the awful silence and desolation of the surrounding desert.

Perennial pools or "nawar."

Everywhere the topography shows that rudimentary and unfinished sculpturing of the earth's surface, characteristic of regions of extreme dryness. As already mentioned, the rivers pass almost without transition from the condition of a mountain torrent to that of a delta. Even where in a somewhat more favoured mountainous district a number of valleys unite to form a channel of some importance, the same particularities are observed on a smaller scale. Just as the larger channel ends abruptly where it leaves the mountain district to break up in a wide fan at the edge of the desert plain, so do the tributaries of that channel end abruptly when they join its course. Usually there is a small fan talus at the termination of each of the secondary ravines. The section of the main valley is

distinct from that of the Helmand, and it receives a scanty supply of water from the streams that flow from the northern and north-eastern slopes of the hills about Amír-Cháh, Saindak, Malik-i-Siáh-Kóh, etc., many of these stream-beds being more or less choked by blown sand. But when the flood of the Helmand is exceptionally abundant, the water of the combined lakes of Seistán rises to the level of the low watershed and flows through the channel of the Shelag river into the Gaud-i-Zirreh. Thus the entire basin of the Helmand becomes tributary to that of the Zirreh lake.

It is only lately that our geographical knowledge of this region has been completed. The true nature of the Shelag river, and the fact that the Gaud-i-Zirreh is a salt-water lake, do not seem to have been fully realized at the time when Mr. Blanford wrote his works upon Persia. The existence of an outlet to the Seistán lakes removes the apparent anomaly mentioned by him, of the Helmand terminating in a fresh-water lake (Quart. Journ. Geol. Soc., Vol. XXIX, p. 495), for the Zirreh lake contains nothing but brine.

not that of a V, with the river channel in its lower part. Supposing such had ever been its shape, the irregular showers of rain which break at intervals making violent torrents of some of its tributaries, while the rest remain perfectly dry, would soon have choked the deeper part of the valley with the boulders rolled down from the secondary ravines, but which the water once spread out in the broader main valley with its more gentle gradient is unable to move further on. Hence the steep and rugged mountain slopes end abruptly on either side of a broad inclined plain, a stony "dasht" in fact, which has a perceptible gradient, but whose section from side to side does not deepen towards a central channel, but is quite horizontal or irregularly notched. The section of the main valley instead of having the shape of a shallow V, is more like a shallow trough with a flat bottom and steep inclined sides. It is only quite at their source that the river-courses resemble at all in their topography an ordinary alpine stream. In many cases after not more than a hundred yards they broaden out and assume the peculiar appearance above described. The cases are very rare where, owing to a perennial flow of water, a valley assumes a normal appearance as in the case of the Shekh Hosein valley. With its clumps of date palms, its cool gushing springs, and its fragrant oleanders, this valley seems so abnormal amidst its barren surroundings that it has become a place of worship and a centre of pilgrimage for the indigenous population whose nominal Mahomedanism is strongly impregnated with fetichism and who have connected many curious myths, probably of very ancient origin, with every physical feature that presents an exceptional character.

These broad winding stony plains, or rather inclined *planes*, constitute the principal means of communication across the mountain ranges, and account for the number of easy passes through which one can travel from one desert into the next one. Except in the most unusual event of a storm these plains are absolutely dry, and even when such an occurrence does take place, the flood which sweeps through it seldom lasts more than one hour when it does last so long as that. At no time does a sheet of water extend right

across the valley, but it rushes through a network of irregular and ever-shifting furrows, rolling along with it large boulders which rattle loudly as they come into collision. These floods by their suddenness constitute a source of danger to the flocks, especially to small animals like sheep and goats, which may be knocked over by the moving boulders and carried away by the flood. The wells where these animals are taken to drink are usually dug in the middle of these broad valleys, and it is a curious sight when the sky becomes threatening to watch the shepherds drive away their flocks on to the surrounding hill slopes where they can await in safety the passing of the flood.

CHAPTER III.—GEOLOGICAL DIVISIONS.

SECTION 1.—INTRODUCTION—MAPS.

I have already mentioned the principal kinds of rocks met with in this region. The marine strata are sediments extending in age from upper cretaceous to upper eocene and interbedded with a large proportion of volcanic rocks. These together with numerous igneous intrusions contribute to form the greatest portion of the hill masses. Considerable areas are occupied by Siwalik strata, and in many regions the older rocks are entirely concealed by modern alluvium and sand dunes. Lastly, in the western portion of the country examined there are several recent volcanoes, one of which still shows signs of activity.

The marine sediments, notwithstanding the enormous extent of their outcrop, belong to little more than one geological division. Of the cretaceous, on the one hand, only the uppermost beds are seen, and, on the other hand, the newest beds observed contain fossils of upper eocene age. The general absence of fossils and the disconnected nature of my observations have not allowed me to draw any divisions through this series. It would have been interesting to make out a succession of horizons and describe them in succession, but there are so many rocks whose exact age cannot be determined that it is impossible to follow such a plan. Petrographical differences do not constitute any guide, for rocks containing fossils that belong to widely different faunas are petrologically very similar. I propose, therefore, to give a few general remarks upon each of the classes of rocks met with, the marine strata, and their accompanying volcanic products, the igneous intrusions, the Siwaliks, and finally the recent deposits. Then I intend to describe the details met with as I proceeded along the line of march. The recent volcanoes forming as they do an adventitious group without any intimate connection with the other rocks will be described separately.

From the list of authors given in Chapter I it may be gathered how scanty is our geological knowledge of the region. On the other hand, the Survey of India maps, most of which are on the scale of quarter-inch to one mile, and some on the half-inch scale, are admirable in every respect, and I regretted not being able to dispose of sufficient time to follow the geological features into the detail which such a perfect delineation of the topography would call for—a task which would be singularly facilitated by the very excellence of such material. Not only was the time at my disposal limited, but as my movements were not always under my direct control, I was not able to turn it always to the best advantage possible. Consequently, I have not ventured to publish any of my work on the quarter-inch scale, except in the case of the Kóh-i-Sultán to the survey of which I devoted the better part of one week (see map No. 2). The rest of the work has been represented on a scale of sixteen miles to one inch. On this reduced scale the sketchy nature of the survey becomes less apparent, and the map may be regarded as fairly accurate in its main outlines (see map No. 1).

Maps available.

SECTION 2.—MARINE STRATA.

(a) *Volcanic Rocks.*

As it is impossible to discover any strict order of succession amongst the marine stratified rocks, it will be more convenient to classify them into volcanic and non-volcanic strata.

These volcanic rocks are often very conspicuous amongst the bare hill ranges owing to their dark colour, while the great height of the ridges which they constitute compared with that of the softer and more easily weathered shales and slates further increases the contrast. They have already been noticed in other parts of Balúchistán and were identified by Mr. Griesbach with the flysch of Europe.

They consist principally of tuffs freely interbedded with every type of marine sediment and varying in coarseness from an agglomerate of huge boulders down to the finest ashes and porcellanites.

The volcanic material occurs mixed in all proportions with the ordinary sedimentary particles, here forming almost the totality of the rock, while at other times we find only a few cinders scattered through a limestone full of fossils.

All these volcanic rocks alternating with nothing but marine sediments are consequently of submarine origin, and real lava-flows are seldom met with. Some great sheets of columnar diorite abundant in the vicinity of Ladis and at Tozgi are probably of the nature of intrusive sills, though belonging perhaps to the same series of eruptive products.

As in the case of the flysch of Europe, the age of these volcanic rocks extends from cretaceous to eocene. As might be expected in the case of strata of this nature, their distribution in space as well as in time is irregular, which will be seen in the chapter devoted to detailed descriptions. But although no definite laws preside over their distribution in space throughout the region examined, yet it would seem that as far as the geological horizons are concerned, they appear to occur more sparingly as we rise through the eocene. In many cases the absence of fossils does not allow of any determination of age, but great thicknesses of slates interbedded with limestone bands full of nummulites which probably correspond in age with the "Ranikot" of Sind are almost free from volcanic material. At Kóh-i-Malik-Siáh where an extensive series of shales is shown conclusively by fossil evidence to belong to that age, there is little, if any, volcanic material. On the other hand at Saindak, strata with a typical "Khirthar" fauna rising up to the base of the "Nari" stage immediately overlie a thick volcanic conglomerate the very coarseness of which would tend to show, however, that it must be of local occurrence. In several instances strata of the "*Cardita beaumonti*" age are interbedded with sediments containing a fair proportion of volcanic material. It is well known that in the neighbourhood of Quetta an important volcanic band separates the hippuritic limestone from the nummulitic strata. Lastly, in the hill called "Kóh-i-Humai," I observed a thick bed of hippuritic limestone resting upon an extensive series of the most typical tuffs.

These cases where the age of the volcanic rocks could be determined with a certain degree of accuracy are unfortunately few compared with those in which no such clue could be discovered: yet they tend generally to show that it is in the upper cretaceous that the eruptions were most abundant, which frames in with the views expressed by Mr. Griesbach as to their being contemporaneous with the great basaltic outflows of the "Deccan trap."

(*b*) *Non-volcanic Rocks.*

The most conspicuous amongst the non-volcanic marine strata are the shales and limestones; the greatest bulk being constituted by shales, while the limestones attract the attention by the manner in which they rise into ridges. In certain regions a more arenaceous facies sets in, the shales being interstratified with sandstones usually highly calcareous; in a few cases there occur conglomerates of small rolled pebbles. As the fragments constituting the sandstones and conglomerates often consist largely of the products of contemporaneous eruptions, the classification of the sediments as volcanic and non-volcanic cannot always be very strictly adhered to.

Just as the volcanic strata with which they are associated, these rocks occur both in a comparatively undisturbed condition, and in regions where folding is displayed to a considerable degree, and their appearance differs accordingly.

The shales here more argillaceous, here more arenaceous, very commonly occur in thinly stratified masses with narrow beds of limestone one foot or two feet thick at intervals. Such is their appearance at Kóh-i-Malik-Siáh where they are of a dull grey colour, and again at Saindak where, in addition to grey, they exhibit many shades of red and yellow. A very common variety is a splintery green-coloured argillaceous rock, no doubt the analogue of the "olive shales" described in other portions of Balúchistán and in Sind. In many places, where associated with volcanic rocks, the shales are highly calcareous and occur as flags often brilliantly coloured as is exhibited

by some very conspicuous rocks round Quetta. The bright coloured varieties not unfrequently contain gypsum.

In the disconnected series of observations made during the journey it was not found possible by means of continuous sections to make out the order of succession in many of the rocks; but so far as could be judged from the cases in which fossil evidence is available, it does not seem that the petrological characters can be of much assistance in determining to what horizon the rocks belong. Thus in districts hitherto described, the olive-coloured shales seem characteristic of the "*Cardita beaumonti*" beds, and in one case at least, at Malik Gatt, such rocks do occur extensively developed in strata of that age. But shales of identical appearance are found also in the Laki hills which contain a Ranikot fauna.

In two of the localities where, owing to the moderate amount of disturbance, the succession of the strata is most clearly exhibited, at Saindak and at Kóh-i-Malik-Siáh, considerable variations are exhibited, although the two places are not far apart. At Kóh-i-Malik-Siáh we find a great thickness (over a thousand feet) of grey shales with some intercalated limestone bands containing *Nummulites*, *Alveolina*, and some Ranikot fossils; these are overlaid by a great mass of limestone several hundred feet thick (see Fig. 13 and Pl. VI); fossils collected at the base of the limestone still belong to Ranikot species, so that the newest date that can be assigned to the great limestone is at the base of the Khirthar. At Saindak, on the other hand, in a series of shales and limestones that bear the greatest resemblance to the strata at Kóh-i-Malik-Siáh, excepting that the shales are frequently bright coloured, the lowest fossiliferous horizon contains in abundance the most characteristic Khirthar forms, and the sequence rises as far up as the Nari stage; the analogue of the great limestone and of the shales of Kóh-i-Malik-Siáh should be looked for consequently below the lowest fossiliferous limestone; yet in the thick series of bright coloured shales and tuffs underlying that rock there is nothing that resembles in the slightest degree the characteristic rocks of Kóh-i-Malik-Siáh.

It is possible that a satisfactory survey might reveal some petrological characters, which taken in conjunction with other particulars might be useful for revealing the true age of particular rocks where the fossil evidence is not available. But nothing of the sort has been detected so far with any certainty. Thus on two occasions, at Kán and at Malik Gatt where some beds were identified, on account of their fossils, with the "*Cardita beaumonti*" stage, there occur some conglomerates; it is not always easy to distinguish a rock of that nature from the volcanic agglomerates so frequent in this region, but in both these instances, the pebbles although volcanic have every appearance of having been rolled. They contain a great many large fossil oysters and other shallow water forms. It may be that, if the relative height of the land was greater during that period, the products of volcanic activity appeared in larger proportion above the sea-level, and this would explain the frequency of conglomeratic beds amongst rocks of that period.

If this be so, then, where other evidence is missing the abundance of conglomerates would favour the notion that the strata with which they are interbedded are upper cretaceous. But the observations made so far are not sufficient to warrant this conclusion, and as to many other rocks, however characteristic may be their appearance, it is doubtful whether they indicate any special horizon. For instance, the great masses of shales with intercalated calcareous sandstone bands that occur in so many districts, such as the Tóba plateau, the ranges east of Nushki, the neighbourhood of Mirui, and many other localities, present, especially when the degree of disturbance is moderate, a most unmistakable aspect. In one instance at Tafui, some of the sandstone bands were found to contain nummulites characteristic of the Khirthar fauna, which shows them to represent locally rocks of the same age as occur elsewhere with a less arenaceous facies; but the very fact of these differences of facies prevents us from concluding that they always belong to one particular stage, and, although so easily recognised in the field, their age cannot be fixed, at present at least, where, as usual, they do not contain any fossils.

Where the rocks are more violently disturbed, with the development, frequently to a considerable degree and over wide areas of slaty cleavage, the differences which mark the various types of shales in their unaltered condition become greatly obliterated. We come across various kinds of slate in which it is difficult to discover what the characters of the rock could originally have been. They often assume quite an archæan facies, and were it not for the distorted nummulites still recognisable in some of the limestone bands, it would be difficult to realise that such rocks could be tertiary. In the neighbourhood of great igneous intrusions, these rocks become still further transformed by contact metamorphism.

Limestones.

The limestones occur as bands of various thickness from a foot upwards and also in considerable masses hundreds of feet thick, when they rise into conspicuous hills. Just as in the case of the other varieties of rocks, the age of these great masses cannot be determined without the help of fossil evidence. The instance above given of Saindak and Kóh-i-Malik-Siáh shows that their development is local, and they seem to occur indifferently and with very similar characters at various geological horizons. The tall crags of Malik Gatt are of the age of the "*Cardita beaumonti*" beds, while considerable limestone hills at Kóh-i-Malik-Siáh, at the Lar Kóh, at Shekh Hosein, are full of nummulites. Owing to the absence of fossils it is not possible to determine the age of those huge masses of limestone that form the Chapar range, and the Gatt-i-Hamun.[1] Petrologically and structurally, no characteristic differences can be detected in any of these rocks. At Amír-Cháh and Kóh-i-Humai, some thick limestones showing sections of hippurites on their weathered surface are of an exceptionally compact and crystalline texture compared with the other limestones of this region.

SECTION 3.—IGNEOUS INTRUSIONS.

The topography as well as the geology of the ranges consisting

[1] These limestones have lately been recognised as upper cretaceous. (See the foot-note on page 58.)

of the above described marine strata is locally varied by the presence of great igneous masses.

These are seldom true granites, but more frequently syenites and diorites, with a granitic holocrystalline structure of varying degrees of coarseness. The nature of the rock varies greatly from place to place, and nearly all the great masses are traversed by dykes of somewhat more basic composition. These basic dykes, the latest results of the series of phenomena that gave rise to these intrusions, occur in many regions, traversing the sedimentary rocks where the larger intrusions are absent.

Age of the intrusions.

These intrusions have been regarded as contemporaneous with the great volcanic outbursts of the "flysch," being in fact subterranean manifestations of the same set of phenomena. This is not exactly the impression which I gathered from the facts observed in the different regions visited.

It has been mentioned above, that the volcanic strata extend right through the upper cretaceous and the greater part of the eocene, but that they become more scanty as the section rises. In almost every instance the great intrusions are found to have been injected amongst strata full of nummulites, so that they are certainly newer than a very great proportion of the observed volcanic rocks; still as there are important volcanic agglomerates apparently of middle eocene age at Saindak, it might be said that the intrusions represent the underground products of some of the later eruptions. Even then, there is this more to be considered. The rocks are holocrystalline, often coarse-grained, and present all the characters of plutonic rocks. They cannot have been formed except under a considerable mass of superincumbent strata, and it is therefore in any case necessary to regard them as much younger than the youngest products of true eruptions that have been observed, so far as the flysch period is concerned.

Another line of reasoning which tends to make them appear much younger in age than the flysch eruptions is as follows. There

is no indication of any unconformity anywhere throughout the whole sequence of marine strata. Even where we find indications of shallow water conditions as amongst some of the *Cardita beaumonti* beds and also in the uppermost Khirthar strata of Saindak, there is no sign anywhere that folding of the beds had commenced. All these deposits seem to have been laid down horizontally without any interruption in a gently subsiding area. Now, the generally vertical trend of the intrusions, so well marked principally in the case of narrow dykes, the absence of any distinct signs of dynamic metamorphism in regions where the stratified rocks are altered to the utmost degree, all tend to show that not only had the folding of the rocks commenced, but that they had reached very nearly the same position where we see them to-day at the time when the plutonic masses were injected.[1]

As my hurried observations may be regarded as not sufficient to establish the conclusions advanced, the alternative explanation might still be offered, that some of the large masses are of the nature of laccolites. This might allow them to be attached to the series of older volcanic phenomena; still it would remain a necessity to regard them as much later than the bulk of the tuffs and more basic eruptions.

In any case the relative ages of at least three groups of igneous rocks, none of which are newer than pliocene, can be very clearly made out as follows:

First, volcanic rocks, properly referable to the flysch; mostly tuffs, and locally intrusive masses, many of which are basic. Their range in time is from upper cretaceous to middle eocene, and they are anterior to the folding of the district.

[1] The case will be mentioned hereafter (page 48) of a volcanic rock which appears to be of Siwalik age, though this is not absolutely certain. This observation might lead one to infer that the granitic and dioritic intrusions represent the deep-seated portion of eruptions of that period. The instance mentioned, even if correct, is too local and isolated to warrant such a conclusion. The granitic intrusions are of such colossal dimensions that, had any eruptions of comparable magnitude taken place at so late a period as the Siwalik age, there could not but exist abundant indications of them; nor is it likely that the cones themselves could have been so completely denuded as to have left no trace.

Second, great intrusions of granites, syenites, and diorites that were injected amongst the rocks during orogenic movements. They cannot be older than upper eocene.

Third, dykes and sills of basalt and dolerite posterior to the period of maximum disturbance, but in all probability older than the Siwaliks.

Hasty as my observations were, I do not believe that there is room for any doubt respecting the newer age of the acid and intermediate plutonic intrusions relatively to the truly volcanic rocks of the "flysch." Moreover, their association may be fortuitous, even though a similar association may be found in other regions—in some parts of Europe, for instance—for this may signify merely that in the latter case the geological history has followed identical phases. Yet in our ignorance regarding the genesis of both volcanic and plutonic rocks at great depths beneath the earth's surface, it is not possible to affirm that there is no connection between them.

Possible relation to the Himalayan granites.

If, on the one hand, it seems advisable to separate these plutonic rocks from the volcanic products of the flysch, on the other hand one is tempted to associate them with the igneous intrusions of the Himalayas. It is quite possible that in the Himalayas, besides an archæan gneiss, there might be later intrusions; and if they belong to the same system as the Balúchistán ones, it would confirm the view expressed by General McMahon and other leading petrologists as to the tertiary age of the Himalayan granites.

The existence of these three successive, if not independent, series constitutes a source of great uncertainty in a hurried examination of the district; for, unless their stratigraphical relations can be made out with accuracy, it is often impossible to decide which of these series many of the observed rocks should be referred to, and hence their relative ages often remain doubtful.

SECTION 4.—SIWALIKS.

It has been mentioned that, besides the marine strata, there are land deposits of Siwalik age. These outcrop in a manner somewhat

different from the great ranges that bear that name along the southern flanks of the Himalayas; the reason is obviously the different physical conformation of the mountains. The Siwaliks in India have resulted from the denudation of that colossal escarpment which terminates the Tibetan plateau on its southern border, and which overlooks the Gangetic plain. The enormous height of the mountains and their geographical situation favour an abundant rainfall and cause all the drainage to escape to the south of the ranges where the permanent deposits resulting from their denudation have accumulated all over the northern plain of India. Denudation had set in actively for long ages before the tangential pressure that folded the mountains had come to a standstill; hence the deposits accumulated on the northern edge of the alluvial plain have shared in the last movements of upheaval, and their tilted strata now constitute the sub-Himalayan ranges.

In Balúchistán, just as in India, the tilted strata of the Siwaliks do represent similarly the last effects of the earth-movements that raised the numerous mountain ranges, and have now perhaps entirely ceased to act. But, instead of the gigantic and compact highland of the Himalayan region, the ranges of much more moderate elevation form numerous strips of high ground separated by lowlying plains. Moreover, although the aggregate thrust may have resulted, as in the case of the Himalayas, in a movement along a roughly north-to-south direction, yet the structure of the ranges shows that the rocks have been forced over the depressed areas along both margins, south as well as north, and the thrust has acted locally at least in a south-to-north direction, the reverse of what is found invariably along the Himalayas. It results from this that where a range runs between two plains it is skirted on either side by Siwalik strata, dipping in either case towards the centre of the range, and giving the section a sort of fanlike appearance. Being thus distributed somewhat evenly right through the region, it follows that the materials that have accumulated to form each outcrop have been derived from areas of drainage which are very small compared to that

from which the materials forming the sub-Himalayan hills were derived. Moreover, the mountains are very much smaller than the Himalayas, and the plains round them being at an altitude greater than that of the Gangetic plain tend to still further diminish their relative height; hence the Siwalik hills in Balúchistán are low in proportion and constitute very insignificant ranges, although the outcrop is often of considerable width. Even before desert conditions had set in to the same degree as at the present day, these less pronounced differences of altitude, and the absence of any such topographical contrast as exists between the Himalayan highland and the Gangetic plain must have favoured a more uniform distribution of the products of disintegration. Thus we find strips of Siwalik strata in narrow depressions between two parallel ridges of one range, though the depression deserves the name of valley rather than that of plain. Such an instance will be described from Tafui in the detailed descriptions (page 47).

As to the general appearance of the strata, it is not necessary to give a detailed description of them, as they are quite similar in appearance to those in the neighbourhood of Pishin and Quetta, which have been frequently described.[1] Throughout the area examined they consist of conglomerates, of friable sandstones, and of clays frequently white or brightly coloured in various tints of pale terra-cotta, ochre, or green. These clays often contain crystals of calcite and gypsum.

It has just been mentioned that, notwithstanding the insignificant altitude of the Siwalik hills, their outcrop frequently stretches across a wide extent of ground. Very often, throughout the entire width of this outcrop, the beds are seen dipping constantly in the same direction with a well marked dip of as much as 20°. If, then,

[1] C. L. Griesbach, Report on the Geology of the section between the Bolán Pass in Balúchistán and Giriskh in Southern Afghánistán. Mem. Geol. Surv. Ind., Vol. XVIII, pp. 18-21. W. T. Blanford, Geological Notes on the Hills in the neigbourhood of the Sind and Punjab Frontier between Quetta and Dera Ghazi Khan. Mem. Geol. Surv. Ind., Vol. XX, p. 180. R. D. Oldham, Sub-recent and recent Deposits of the valley plains of Quetta, Pishin and the Dasht-i-Beaaolat. Rec. Geol. Surv. Ind., Vol. XXV, p. 36.

we regarded the sequence as a normal one, it would be necessary to admit an incredible thickness of strata rendered very improbable at once by the dwarfed proportion of the ranges, while beneath what would be the highest beds exposed the oldest beds would have to be sunk to a depth quite inexplicable. No doubt the structure is therefore an imbricated one, as has been shown to be the case with the sub-Himalayan ranges; but observations are far too scanty to place upon the map the position of any of the lines along which the rocks have yielded.

The tilted position of these strata is evidence of the latest effects of upheaval produced by the folding of the region. When they became displaced the entire region was already a land area, perhaps already one of closed drainage. In fact, the conglomerates are very similar to those which are still being deposited at the present day, or at least were deposited up to a very recent period before the dessication of the country became so absolute as it is now. But as to their position in the geological sequence, it cannot be fixed in the case of any of the rocks which I saw, for I did not come across any fossils. Various considerations, however, make it evident that the age of the newest of these strata must be placed back well in the tertiary, probably before the end of the pliocene. Upon their upturned and denuded edges rest with complete unconformity the recent deposits which cover the desert plains. Although where there is still a certain amount of rainfall, these accumulations may still be in process of formation, yet the enormous thickness to which they have been piled up shows that those low down in the sections have been deposited at a very remote period. Since the last upheavals sufficient time has elapsed for the accumulation of these enormous deposits, these in turn have been deeply eroded, physical changes of great importance have had time to take place, huge volcanic cones have been built up and again denuded away, and yet nowhere can the slightest indication be found of disturbance or earth-movements of any kind.

These considerations allow us to discuss at once both the age of the Siwalik hills and of the more important ranges with which they are associated. Throughout a series of strata extending from upper cretaceous to upper eocene there is nowhere any sign of erosion or unconformity. Therefore we must admit that until the last stages of the eocene the upheaval of the ranges had not commenced. On the other hand, the last chapter in the history of the upheaval, as illustrated by the Siwalik strata, had ended before the end of the pliocene. Therefore the folding of this large area, the upheaval of all the ranges, the metamorphism of shales into slates, the intrusion of great igneous masses, the conversion of the sea into a land area, the denudation which furnished the materials for the Siwaliks, and finally the uplifting of these latter ranges, must have all taken place within a relatively short period of the earth's history. The upheaval may have commenced before the end of the eocene, it attained its maximum during the miocene period and came to an end with the pliocene. Whatever may be the date of upheaval of the Himalayas, whose age has given rise to some discussion, the facts will not allow much doubt so far as the Balúchistán area is concerned, as to the comparatively late period at which these mountains were upheaved and the comparatively short period necessary for the process.[1]

Age of the mountain ranges.

The data available are perhaps hardly sufficient to say that the tangential forces have entirely ceased to act. Observations are far too scanty and extend over too brief a period to decide whether any small changes of relative level are taking place. The undisturbed condition of thick deposits of recent gravel and of the volcanic cones may show merely that those areas where they have been observed have not suffered folding, and we know that large areas have been comparatively exempt from folding throughout

[1] "That the elevation of the Southern Persian mountains is of no high geological antiquity, we may infer from the fact that ranges 10,000 feet high consist of nummulitic rocks, that the gyposiferous beds, which are newer than the nummulitics, are found at an elevation of 7,000 feet above the sea, and the Makrán formations, which are probably not older than pliocene, attain almost an equal height." W. T. Blanford. Quart. Journ. Geol. Soc., Vol. XXIX, p. 501.

the whole period of orogenic movements (see *ante*, page 7). Nevertheless, considering, on the one hand, the short time, geologically speaking, that was necessary to produce the bulk of the upheaval, and, on the other hand, the indistinctness of any evidence of recent movements, it seems reasonable to admit that if the orogenic forces have not entirely ceased, at least they have dwindled down to a very low ebb.[1]

It is true that the whole of this region is frequently visited by earthquakes, which shows that the earth's crust is still there in a state of unstable equilibrium. But it is not proved that these seisms are connected with folding of the strata.

Volcanic rocks perhaps of Siwalik age.

An observation, unfortunately somewhat doubtful, which was made at Robát, would, if confirmed, indicate the existence of one link at least, between the recent epoch and the period at which the Siwalik strata were deposited. Throughout the enormous areas occupied by outcrops of the Siwaliks in India I do not know of any instance of these strata having been found affected by igneous intrusions, or containing any volcanic material other than that derived from older rocks. On the right bank of the Robát river, near Pain Robát, are some highly tilted strata consisting of conglomerates and shales which I first took to be Siwaliks, but which are so much concealed by recent gravels that it is difficult to make sure of their characters. On finding one of these strata to be a volcanic rock, I concluded that these sediments cannot be the Siwaliks, but the older rocks of the flysch period, which are represented by well developed tuffs and agglomerates in some of the neighbouring sections, and whose typical appearance seemed masked owing to the imperfection of the exposure. Microscopic examination shows that the rock exhibits a degree of freshness which is not observed in any of the volcanic products that can be assigned with certainty to the flysch period. The first impression given by the associated strata as being Siwalik may therefore have

[1] Mr. Griesbach has shown that anticlinal and synclinal flexures are still in process of formation in certain parts of Turkistan. Rec. Geol. Surv. Ind., Vol. XIX, pp. 260-261.

been correct, and this rock may indicate that the great eruptions which in recent and sub-recent times culminated in the building up of the gigantic cones of Eastern Persia had already commenced in Siwalik times. This rock, together with some curious basic dykes of very recent aspect found in the same neighbourhood, will be again referred to in Part II of this Memoir (see page 88).

SECTION 5.—RECENT AND SUB-RECENT DEPOSITS.

Under this heading come all the rocks which have been deposited since the termination of the upheaval of the ranges. Their principal characteristics have been mentioned when the hydrography of the district was described. There it was mentioned how they have filled with conglomerates and sands the great depressions that lie between the groups of mountains; how they cover with a horizontal layer of silt the plains that once were lakes; how they have accumulated to form the gigantic talus or "daman" skirting the mountains.

In a country where the rainfall is so scanty and irregular, where the hydrography is in quite a rudimentary condition, it naturally follows that we cannot expect to find the section of the plain to exhibit those beautifully regular curves which any river or valley shows when followed from mountain to sea-coast or lake basin in a region where the rainfall is normal. Undulations barely perceptible to the eye in such alluvial plains when plotted on an exaggerated vertical scale are found to follow very definite laws, taking the shape of a parabolic curve concave towards the sky. The desert plain which, when seen from a height, also appears quite flat, does exhibit shallow undulations leading to well-marked differences of level; but these instead of obeying definite laws are distributed quite irregularly. The topographical survey of this desert has not been carried to that degree of minute detail which would allow this to be shown by representations of actual sections of the ground; but it is strikingly illustrated by the juxtaposition of numerous independent basins of drainage, often at well-marked

differences of level, though they may occur in close proximity, as has been mentioned in the chapter on hydrography.

Yet, amidst all this confusion, there are some curiously regular features: such are the long lines of terraces formed by the conglomerates stretching over wide areas. It frequently happens that the traveller following the narrow camel track beaten out of the stone-strewn "dasht" along what seems an interminable plain, suddenly finds himself on the edge of an escarpment and sees another plain below him some thirty or forty feet lower. This lower ground may again slope gently down to another step-like escarpment, and there may be thus three or four of these superposed terraces. If the country had been more thoroughly examined it would have been found probably that these lines of terraces form concentric belts surrounding at a distance some of the larger lake basins. They admit of only one explanation, that they represent ancient shore lines of great lakes, which now have either dried up entirely or are reduced to insignificant shallow marshes or salt swamps.[1] The successive lines of escarpment would represent temporary periods of rest during the gradual drying up of these great masses of water. The level of the waters being constant during a certain period constituted temporarily what the Americans call a "base-level" of erosion; the surface of the lake was the lowest level to which running water could carry down pebbles and boulders, and thus for the time being the shore of the lake was the limit of the accumulation of conglomerates.

Gravel terraces.

I visited one of these lake basins, the Lora-Hamun, now absolutely dessicated, an endless "pat" or plain of sun-cracked mud of a pale yellow colour with great patches here and there of saline efflorescence, and absolutely destitute

Evidence of a change in the physical conditions.

[1] Most of the terraces which I have observed belong to the north, north-east, and north-west margin of the great depression whose lowest portion is occupied by the Hamun-i-Mashkhel and other dried-up ponds. That similar terraces are found on the southern margin of the depression is shown by one of the sketches in General McGregor's "Wanderings in Balochistan," p. 129. (These gravel terraces are also mentioned, pp. 138, 154, etc.) The terraces surrounding the depression once occupied by the former lake of Seistán are mentioned in H. W. Bellew's "Record of the March of the Mission to Seistán."

of vegetation except in the immediate vicinity of the shore line. Along its western shores some stream-beds terminate amongst shallow marshes of stagnant water and mud banks covered with decayed reeds, but none of this water reaches the absolutely dry plain of the "Hamun," which only takes the appearance of a lake when the mirage floats over its surface creating a fantastic geography of lowlying promontories and groups of scattered islands. These islands are small hills of ancient volcanic rocks and limestones of the "flysch" period surrounded on all sides by the pale yellow silt; but a very remarkable feature presented by them is that their slopes exhibit sometimes almost up to the very summit patches, more or less washed down by occasional showers of rain, of the very same buff-coloured mud which covers the floor of the dried-up lake. It is impossible that this mud should have been derived from the weathering of these low mounds of ancient lava, which are too small to allow of any such differentiation of the products of weathering. The only products of denudation derived from them are angular pebbles, dark coloured like the hills themselves on whose slopes they lay scattered. On the hills called Kaftani, near the south-western shore of the "Hamun," the lower portion of these mud deposits though ravined by the rain still presents a terraced outline, and denudation has exposed sections in which strings of angular pebbles from the tuffs of the hill rest upon strata of the buff-coloured mud. It is quite evident that this mud washed down in former times by rivers was deposited in the still water of a lake, just as the deposit of the same nature which covers its dried-up floor. Moreover, as they are found at all heights along the slopes of the hill, it shows that these were at that time entirely submerged; further, that a large sheet of water then existed whose surface rose to a height fifty feet or more above the floor of the dried-up lake, and that the Lora-Hamun covered a surface three or four times as extensive as the plain which now bears that name.

When speaking of the "fan-taluses" under the heading of hydrography, it was mentioned how the watercourses at the present

day pass without any transition from the condition of a mountain torrent to that of a delta, the fan-talus being in fact nothing but a small delta. This explains the enormous accumulation of talus in the immediate vicinity of the mountains. But in former times it is evident that the presence of such important sheets of water induced a much more abundant rainfall and thus were the pebbles distributed over the entire width of the desert.

These lakes at length shared the fate of all inland drainage areas. The water evaporated from their surface did not all return in the shape of rain, a certain amount was always lost, and the clouds originating from the evaporation of sea-water could not be counted upon to make good the loss. It is one of the fundamental facts in physical geography that the increased altitude of the land in mountainous regions causing the vapour-laden atmosphere blown from the sea to rise to higher and colder strata in the air, determines the precipitation of rain on the slopes of the mountains turned towards the sea. When the clouds reach the opposite slope they descend once more to lower altitudes and the air is no longer saturated. In this way the inland drainage area will never obtain enough moisture from the sea to repair its own losses, and its ultimate fate must in all cases become irrevocably its conversion into a desert.

These are of course well-known principles of physical geography, but if I draw attention to them here it is on account of the widespread notion that the decay of such countries as Balúchistán is due to bad government and anarchy. This is a fallacy of a very common type which consists in mistaking the cause for the effect. Of course, there is no doubt that such an ill-advised policy as the disafforesting of mountains may accelerate the ruin of the country. But a country physically situated like Balúchistán, whether it be well or badly governed, is inevitably doomed to ruin. It is merely a matter of time, but ultimately it must get beyond the scope of human control, owing to the desert conditions which must of necessity become more and more aggravated. There is plenty of

evidence that the process of dessication has gone on to a marked degree even within historical times. As the region became unfit for cultivation, the population gradually dwindled until the few tribes that still lingered back were forced by necessity to seek in pillage and robbery the sustenance that industry could no longer provide them with. It is the natural aggravation of physical difficulties which engendered anarchy, not, as is usually thought, anarchy which has caused the decay of the land.

This erroneous impression is still further encouraged by the apparent revival of prosperity which takes place when nations provided with all the resources of a well-equipped civilisation take over the government of these countries. This is due to a double cause: First, the protection against robbery and misrule, which permits the more enterprising and industrious part of the population to pursue their occupations in peace; secondly, a better dispensation, by means of improved irrigation, increased means of communication, and so forth, of those natural resources which still exist. It is a better employment of those resources, but the resources themselves are decreasing. Where there used to be no culitivation, but now, owing to an artesian well or a "kárêz" an artificial oasis has been created, this indeed seems an improvement. But it must be remembered that the rainfall is ever decreasing, that it is the ultimate source from which all the water used for irrigation is derived, and that consequently the supply is gradually dwindling. Of late years kárêzes have dried up at Quetta, which had given an abundant supply since more than a century, and this notwithstanding that the work is kept in perfect repair.

Ancient terraced fields.

In one of the regions which I visited, amongst the mountains of the State of Kharan, there are some very interesting relics which bear evidence to a very different set of physical conditions than those that prevail at the present day. In all the valleys round Zard there are to be seen hundreds of stone walls which are called "górband" or "dams of the infidels." Sometimes they stretch right across the flat pebbly floors

of the great valleys which, for want of a better name, are termed "rivers," notwithstanding the somewhat sarcastic ring there is about that appellation. They also occur across the entrance to most of the tributary ravines and at various points across their course up to considerable heights above the main valley. The country is quite uninhabitable for want of water, and yet there is no doubt about the nature of these walls which are similar to works erected to the present day in many regions of Balúchistán and Persia, being in fact nothing but terraced fields. But the careful way in which they are built gives them an appearance of permanency which one would look for in vain amongst the works of the present generation. In many cases they still hold back the soil, formerly cultivated, which has been artificially heaped up against them. This soil is absolutely similar to that which covers the great alluvial plains of "pat." No such material is to be found anywhere amongst the hills where the walls have been built, and it must have been brought at the cost of considerable labour from the great desert plain south of the mountains. The absence of any canals, the great height to which the walls are found up the tributary ravines, shows that the fields were not watered by means of some general scheme of irrigation with canals deriving their supply from some reservoir placed at a greater altitude. Perennial springs, now everywhere dried up, must have existed in all the ravines where these remains are found, which shows how much greater the rainfall must have been formerly.

Recent date of dessication.

The modern inhabitants of Kharan in calling these structures "górband" or "dams of the infidels" attribute their erection to the fire-worshippers. Degraded as they are to a condition bordering on the status of savages, they have lost sight of all accurate historical notions. The attribution of any work to the "fire-worshippers" simply means that they look upon it as very old, older than the first Mahomedan settlements. They have not forgotten, however, what the walls really are, that they are terraced fields, and the legend says that the inhabitants who built them brought all the soil in bags which they carried on their

backs, from the desert to the south (such an act is regarded as very sinful by the Balúch who consider manual labour degrading to human dignity). It is more probable that the soil was carried on the backs of beasts of burden rather than on that of men, but the tradition is no doubt an echo of the immense amount of labour which this work necessitated. At all events the greatness itself of the undertaking shows that the returns of the work must have made it worth the trouble which they took, and that what is now a barren desert was once the home of a prosperous community. It is certainly not improbable that these people might have been originally the fire-worshippers, but I am inclined to think that similar works continued to be erected long after the first Mahomedan settlements. In these same mountains of Kharan there are ancient Mahomedan cemetries in which the tombs and the wall surrounding them are built exactly in the same manner as the walls of the terraced fields, being made of roughly-shaped stones disposed in very regular layers. Nowhere in Balúchistán could a work of that nature be built at the present day, the modern graves are mere mounds of earth clumsily decorated with boulders, or occasionally with pieces of weathered travertine. The tombs just mentioned seem, on the other hand, to be the work of the same hands that used to build the terraced fields. I do not know enough of the history of the region to assign any date to them, but the mere fact of their being Mahomedan shows at what a very recent date we must place the final dessication of these mountains.[1]

Sand dunes.

This complete dessication of the district has allowed the development of the most characteristic feature of desert scenery, the accumulation of wind-borne sand. I have nothing to add to the descriptions which have been

[1] "From the accounts given by ancient writers, it appears highly probable that the population of Persia was much greater, and the cultivated land far more extensive 2,000 years ago than at present; and this may have been due to the country being more fertile in consequence of the rainfall being greater. Some alteration may be due to the extirpation of trees and bushes, the consequent destruction of soil and increased evaporation; but this alone will scarcely account for the change which has taken place." W. T. Blanford. Quart. Journ. Geol. Soc., Vol. XXIX (1873), p. 500.

given of similar formations by many authors. Of the two kinds of sandhills distinguished by Mr. Oldham in the Indian desert,[1] only the "transverse" type is exhibited in the localities which I have visited, while the cresent-shaped dunes called "barchanes" or "medanos" are everywhere developed with the most typical characters.[2] Sometimes the dunes coalesce into huge masses which are slowly advancing over the plains, and against which even the mountains no longer form a barrier: the sand is blown over the crests of the ranges and many a valley is being buried beneath a shroud of sand. Entire ranges of low hills have already been buried in the region between Amír-Cháh and Saindak where some of the sandhills rise to heights of as much as 200 feet. The sandhills when newly-formed at least are extremely permeable; for instance, at Amír-Cháh there is a river-bed which cuts through the hill range forming a narrow gorge or "tangi," beyond which it is cut across by a broad belt of sandhills. Some ten miles further the river-bed once more re-appears from beneath the sand dunes. It is joined by several tributaries, one of which bears the name of Sam river, and finally finds its way to the Gaud-i-Zirreh. On one occasion while I was at Amír-Cháh in the night of the 11th to the 12th of March, there was a heavy shower of rain which converted the dried up stream-bed into a raging torrent. On the following morning, Mr. Tate went to see whether the sandhills had kept back any body of water where they cut across the river-bed; but this place was perfectly dry, notwithstanding that small pools had been left in other portions of the river-bed. I ignore whether any flow of water appeared from beneath the sand where the river-course once more comes to light.

[1] Manual of the Geology of India, 2nd edition, p. 455.

[2] The question of sand dunes has been studied both from a theoretical and an experimental point of view by Vaughan Cornish: "On the formation of sand dunes." Geogr. Journ., Vol. XI (1897), pp. 278-309. For descriptions of the sand dunes in the Balúchistán desert, see Pottinger, "Travels in Baluchistan and Sinde," p. 132; McGregor, "Wanderings in Baluchistan," p. 157; C. L. Griesbach, Rec. Geol. Surv. Ind., Vol. XVIII (1885), p. 59.

Nevertheless, where the sandhills spread over a district liable to be flooded they must influence the sedimentation of mud carried by the water, and may ultimately by its gradual accumulation give rise to a closed impermeable basin. I am inclined to think that an influence of this sort has been at work in the formation of the small perennial ponds or "nawars;" for both of those which I saw are surrounded by sand dunes.

Recent volcanic formations.

In addition to these alluvial and æolian deposits there are other recent formations of volcanic origin. These consist of various accumulations of lavas and cinders, and also the deposits of mineral springs which have produced large masses of travertine. They will be described in a separate chapter.

PART II.

DETAILED DESCRIPTIONS.

CHAPTER I.—DESCRIPTION OF SECTIONS.

Neighbourhood of Nushki.

Nushki lies at the eastern edge of a great desert which, north of Nushki itself, is bounded on the east by an almost rectilinear line of escarpments. This long line of escarpments is the western limit of a broad range composed of many parallel ridges which bears the name of Kójak and Khwája Amrán in districts further north. Nearer Nushki it bears on the maps the name of Sarlat range. To the east this range, or rather this aggregate of ridges, borders on to a plain which on the maps bears successively, from south to north, the names of "Gurgina," "Shórarúd," and "Peshin." Again east of this latter plain there is another range which, in the neighbourhood of Quetta, is called the "Ghaziaband" range from the name of the "Ghaziaband pass," where it consists of shales and nummulitic limestone; further south the proportion of limestone increases and the range is fringed on either side by tilted Siwalik strata. As to the great broad range bordering on to the desert, and which bears successively the names of "Sarlat," "Khwája Amrán," "Kójak," and continues northwards as the "Tóba plateau," it consists, east of Nushki, of exactly the same rocks that constitute it further north in the "Tóba" region. These rocks are alternating beds of grey splintery shales and calcareous sandstones. In the eastern part of the range these show numerous synclinal and anticlinal folds. It often happens that the horizontal, or nearly horizontal strata along the axis of a syncline or anticline are preserved in the upper portion of a hill, and the broad sandstone bands alternating with the shales causes these summits to take a very peculiar stepped appearance under the influence of

Siwaliks of the Ghaziaband range.

denudation. Occasionally limestone bands occur, which sometimes are full of broken fragments of shells, but nowhere have any fossils been met with in a sufficiently good state of preservation to be identified. Veins of calcite are abundant in the shales and calcareous sandstones.

"Kójak shales."

Similar rocks occur along the northern continuation of the ranges in the Kójak pass where they are greatly contorted; from that locality they have derived the name of "Kójak shales."

The section, Fig. 6, has been drawn to give a general idea of the kind of disturbance exhibited in this region. It is of a somewhat diagrammatic nature, as it is drawn approximately at right angles to the line of strike, while the line of march was really an oblique one, and it unites therefore features which should be shown on several separate sections. But as the same type of structure continues for great distances along the strike, the diagram gives a fairly accurate idea of the kind of structure. The section represents the eastern part of the range as seen along the road to Nushki; it consists of a number of parallel ridges extending between the plain of "Gurgina," there called "Kardagap" to the east, and to the west a rather broad valley called "Kishingi." It will be seen that the disturbance is of a somewhat moderate character, and except in one place there is no sign of slaty cleavage. If the same section had been continued about an equal distance further west, we would have reached the escarpment that overlooks the desert. It is not necessary to draw this second part of the section, as it would be purely diagrammatic. Moreover, the structure remains exactly the same until close to the neighbourhood of the final escarpment. At a distance of about two miles from that limit the character of the rock changes somewhat rapidly. First the folds become much sharper and more numerous and then cleavage sets in, transforming all the rocks into one mass of soft silky slates, amongst which no original structure can be recognized. Wherever the rocks are thus altered, assuming the facies of the "Kójak shales," quartz veins are largely developed in addition to the usual calcite ones. The cleavage dips very steadily to the

east-south-east, away from the desert depression, giving one the impression that the tangential force which folded the ranges, acted here from east to west. The rocks of the mountainous region are probably forced over the desert depression along an overthrust plane. The presence of Siwalik strata also dipping east, all along the western foot of the hills, further strengthens this supposition.

Probable existence of inverted fault bordering the desert depression.

A few miles north of Nushki some hills of limestones and tuff intervene between the main range with its fringe of Siwaliks to the east, and the desert to the west. This is represented in section, Fig. 3. To the west are black volcanic rocks, whose structure it is difficult to make out; apparently resting upon these, with a general eastern dip, but much crushed and contorted are some limestones of various colours forming small hills. The limestones are pink and flaggy or else green and shaly; others are white, more massive, and considerably brecciated. The limestone and the igneous rocks seem to have re-acted upon one another giving rise to green alteration products. The easternmost limestones are massive, brecciated, unaccompanied by any volcanic rocks, but full of nummulites (*d*). Judging by the dip alone, it would seem that the shales and sandstones of the principal range rest upon this nummulitic limestone, but as it is very probable that an inverted fault runs all along the foot of that principal range, it is difficult to tell in the absence of fossil evidence what the real relations of the rock can be; the presence of a band of Siwaliks (*e*) between the nummulitic limestone and the slates makes it all the more likely that a fault exists here.

It has been mentioned that all along the western margin of the great range where it borders upon the desert, slaty cleavage is highly developed. The character of the rocks is so disguised by this peculiarity that they might be taken for palæozoic strata, and have been several times described as such. In fact, this was my own opinion when I first saw them. Afterwards, however, I observed that they pass quite gradually into the shales and sandstones of the central and eastern portions of the range. Nowhere can any rigid line of

demarcation be drawn between them, and the slates are nothing more than the shales altered by dynamic metamorphism. Similar slates will be described in other regions occupying large areas, and with intercalated limestone bands full of nummulites.

Fault or fissure.

Along the western edge of the principal range, where it borders upon the desert, and where, owing to various indications, it seems probable that there runs the outcrop of an inverted fault or overthrust, there exists a feature which has been variously described as a "fault" or "earthquake crack." It is quite conceivable that it should be related to the previously existing inverted fault.

Siwaliks.

The Siwaliks shown in section, Fig. 3, continue southwards with a very constant line of strike, more or less concealed at times by recent deposits. They form a remarkably rectilinear line of conspicuous low hills across the Nushki plain, and south of Nushki separate into two branches. The eastern branch continues southwards along the south-west strike of the main range; the western branch strikes south-west and marks the commencement of a long series of Siwalik ranges which may be followed westwards for a great distance, fringing the southern borders of a range of older rocks which will be described further.

The strata usually dip at about 40° in an easterly direction. They consist of bright red conglomerates, interbedded with sandstones of various colours. Lower down the section, the sandstones are interbedded with clays of various colours, pink, white, green, and purple ($\frac{13}{934}$). Rifts and caverns in the beds of conglomerate running at right angles to the strike have been filled with a curious calcareous breccia ($\frac{13}{935}$).[1]

Talus formations.

All along the foot of the main range is an enormous talus spreading into the plain of the stony desert. The portion north of Nushki was mentioned when dealing with hydrography as an illustration of the considerable

[1] These and similar numbers are those of the Register of the Survey Collections.

importance assumed by these recent structures, and of the peculiar disposition of the innumerable parallel ravines which scour their slope. Immediately east of Nushki is a remarkable hill consisting entirely of recent conglomerates and gravels up to its summit which reaches up to a height of 4,473 feet according to the map, about the same height as many of the neighbouring ridges of older rocks out of the débris of which it is built. On one side, to the west, the beds of gravel and conglomerate dip towards the plain, at an angle of about 20°, about the same as the slope of the hill; the eastern side is a gigantic precipitous cliff at the foot of which the river "Khisar" winds its way. It is difficult to understand how these recent beds have been heaped up to such an altitude; perhaps they represent an ancient fan deposit of the river Khisar itself when the water supply was more abundant, and before its bed was excavated to its present depth. Whatever may be its true nature, it is evident that this deposit is, comparatively speaking, of great antiquity, for it has been formed under physical conditions widely different from those that prevail at the present day, and it has been considerably denuded since the time of its formation, presenting as it does a steep cliff on one side, and on the other a slope scoured by deep ravines. Yet its formation is posterior to any earth-movement in the district, for its beds are absolutely undisturbed, and a very well exposed section at the northern end of the hill shows them resting with complete unconformity upon the Siwalik strata highly tilted in the opposite direction. This is one illustration of a question which has been touched upon several times, that is, the absence of any distinct evidence of folding within comparatively recent times in this region at least.

Ranges south-west of Nushki.

The great range of shales and sandstones that bears successively the names of Kójak, Khwája Amrán, and Sarlat, continues southwards passed Nushki, with the same extremely regular strike S. by E. I have not followed this southern extension; according to the

map, it is not until it reaches a latitude of 28° that its strike begins to take a more distinct S. W. trend. But in the immediate neighbourhood of Nushki is the origin of two ranges with a S. W. strike which soon diverge from one another in a sheaf-like manner, their strike becoming more and more nearly west. All these ranges are separated from one another by great desert plains.

The northernmost and innermost of these two ranges forms a line of low hills, south of the dried-up bed, which constitutes the lower course of the Lora river; it follows at a distance the same direction as the river, up to the southern extremity of the Lora Hamun. South-west of the Hamun it rises to a greater height forming a conspicuous hill called the "Chapar range." Beyond this occurs a confused mass of low hills without any very definite direction of strike. North of this range the desert spreads uninterrupted as far as the Helmand and its tributaries; south of it, a narrow strip of desert plain extending from Nushki to Dalbandin separates it from the next range to the south.

This next range which also possesses no general name is of much greater importance; one of its summits, the Rás Kóh, rising to nearly 10,000 ft. It runs between the Nushki-Dalbandin depression on the north and the Kharan plain to the south. Its strike which is south-west in the neighbourhood of Nushki becomes gradually more westerly, and, about latitude 64°, the hills sink beneath superficial deposits where the Dalbandin and Kharan deserts unite into one great plain in the midst of which lies the Hamun-i-Mashkhel.

I have had occasion to examine this range in several places, and the following is an account of the principal points of interest that were noticed.

Hills between the Nushki and Dalbandin desert to the north and the Kharan desert to the south.

North-western extremity of the range, near Nushki.

The extremity of the range in the neighbourhood of the village of Bághak consists of a few low ridges striking S. by W. The rocks are crumpled to such an extent that it is difficult to tell in which

direction the section ascends; it more probably ascends when travelled across from west to east as in the case of the section described north of Nushki (page 42). The westernmost and probably lowermost rocks are calcareous shales whose deep brilliant hues, red and green, are probably due to the admixture of volcanic material; they are associated with conglomeratic and pebbly bands in which the fragments consist of volcanic materials but which exhibit a distinctly waterworn appearance. Continuing eastwards, the same rocks become interbedded with limestones some of which are arenaceous; they contain a few shattered fossils mostly species of *Cerithium* that appear identical with others met with elsewhere together with Ranikot fossils. Other instances will be noticed where these conglomerates are found associated with beds containing a Ranikot fauna (page 58). Further east is a thicker bedded limestone rising to form a ridge in which a violent anticlinal flexure can be recognised. Beyond it come some more variegated shales and then tall crags of nummulitic limestone. This forms the culminating point of the ridge; on the eastern slopes, we meet with more variegated shales, and again nummulitic limestone, the conditions being too much disturbed to decide whether it is a repetition or not of the first one. Lastly, a broad plain extends to the foot of the Siwalik hills that border the great Nushki range.

Tafui section.

In a S. by W. direction, these ranges rapidly increase in height, reaching an altitude of 5,825 ft. to the east of "Jaurakin." I did not examine this portion of the range, but a little further, in the neighbourhood of "Tafui hill," it still consists of tertiary shales and limestones. The total width of the range increases as well as its height, and beyond Tafui another kind of rock sets in, in addition to those already mentioned: these are tuffs similar to those that were first mentioned in the section north of Nushki; they skirt the north-western edge of the range forming black ridges which gradually increase in height; seen from the plain on the north side they present the appearance of a great black wall which conceals all the tertiary ridges to the south-east.

The section, Fig. 16, is taken about four miles to the south-west of Tafui hill. The tuffs *a* are succeeded by a limestone which apparently underlies them, but it is quite possible that the dip is inverted: about three miles further on the road that leads to the peak called Sheikh Hosein, a limestone similarly placed and containing nummulites is seen to distinctly overlie the volcanic rocks. In the present instance the limestone *b* is altered to such an extent that no fossils can be recognised. Next come green slates *c* with very well marked cleavage. Next we find a great longitudinal valley separating the range into two principal masses and occupied by a syncline of Siwaliks. These consist of the usual sandstones, coloured clays, and conglomerates. At *k* the junction with the older rocks is very clearly exposed showing a complete unconformity: the lowermost bed of the Siwaliks is a conglomerate containing rock fragments and even fossils derived from the strata *d*. The axis of the synclinal trough is very distinctly exposed in the shape of a well-marked flexure, the uppermost bed consisting of conglomerate. Upon the Siwaliks rest great horizontal masses of recent gravels.

The strata at *d* are shales and sandstones with a few very narrow bands of limestone, absolutely similar in appearance to the rocks of the great range east of Nushki (Fig. 6); but in the present instance, some recognisable fossils were found in a few beds of limestone or calcareous sandstone: there are very large individuals of *Nummulites granulosa*, d' A. and H., a fossil charaeteristic of Khirthar beds met with in other regions; it is associated with numerous specimens of an undescribed nummulite which also occurs abundantly amongst the Khirthar strata of Saindak (page 83) In the present instance therefore these shales and arenaceous sandstones may be safely ascribed to the Khirthar stage. The dips are high, but the effects of compression are very moderate especially when compared with the disturbed condition of the slates *c*. But as we continue travelling across the section, the effects of compression gradually increase until we get at *e* the most intense slaty

cleavage; yet the contortions recognisable in the rocks are so numerous that it does not seem that the section either ascends or descends, and the succession of argillaceous, arenaceous, and calcareous beds is so similar to what we found at *d*, that the beds are no doubt the same altered by metamorphism: the passage is quite gradual, and even where the slaty facies is most developed, nummulites are still recognisable. Thus it is quite possible that the enormous masses of highly altered slates that form such a marked feature of Balúchistán may largely consist of rocks belonging to so late a period as the middle or even upper eocene. Just as in the range east of Nushki, this slaty alteration is accompanied by a great development of quartz veins.

Lastly at *f*, is another limestone succeeded by more Siwaliks *h*, beyond which stretches the high level plain of Kharan *i*, covered with stony alluvium. The hills at *j*, dip S. E., but were only seen from a distance.

Shekh Hosein.

Following the ranges still further in a south-west direction, we find that the strike becomes more decidedly south-west and the height keeps on increasing. The conspicuous limestone peak of Shekh Hosein rises to a height of 6,875 feet. The hills consist of exactly the same rocks with a gradually increasing mass of volcanic strata along their north-western border. Not only do these volcanic rocks form a continuous barrier skirting the main range, but isolated hills show through the alluvium at distances of as much as two miles from the mountains: of such a nature is the curious little hill called "Mall Mekh." These tuffs, consisting of fragments sometimes almost large enough to make them deserve the name of conglomerate, are associated with finer grained ash-beds and frequently with bright-coloured limestones. They belong to the "flysch" series, but in the present case their age is probably newer than cretaceous, or at least the uppermost beds are lower eocene, for as was already mentioned (page 47), on the road that leads to the ziárat of Sheikh Hosein we find them immediately overlaid by a limestone containing

nummulites. Moreover, this nummulitic limestone is itself succeeded by beds which still contain a large proportion of volcanic material showing that the volcanic activity had not ceased yet. The fossils in this lowest nummulitic limestone consist of species of *Nummulites* and *Alveolina* met with elsewhere in strata of the Ranikot age.

As to the tall range whose highest peak bears the name of Shekh Hosein, it also consists of nummulitic limestone, but the beds here are crushed and disturbed to such an extent that their succession could not be unravelled during the short time at my disposal.

These unusually tall peaks favour atmospheric precipitation, moisture collects upon the steep limestone slopes and even rain occurs occasionally. These favourable conditions have given rise to a perennial spring in the neighbourhood of which is a "ziárat" resorted to by pilgrims who come even from great distances. The ziárat is consecrated to "Shekh Hosein," a mythical saint round whom many legends have gathered. The limestone of the neighbouring hills has a concretionary structure, causing it to weather out in large spherical boulders. These are said to be the remains of an invading army of Moguls who were sent to attack the saint. The "Shekh" turned them all into stones and the boulders are the heads of the miscreants that rolled down the valley. The valley is occupied by a perennial stream which has allowed the creation of fields cultivated by the faqirs who take care of the "ziárat."

Section along the Nimik Pass.

The next pass leading across the ranges into the Kharan plain is called the "Nimik Pass." Just as in the sections above described, near Tafui and Shekh Hosein, the north-western portion of the ranges consists of bedded tuffs of the "flysch" period (see Fig. 18). It has been mentioned that their importance gradually increases as we follow the strike of the ranges in a south-west direction. Near the entrance to the Nimik Pass they have spread out, forming several tall parallel ridges conspicuous for their rugged outline and black colour. The outermost range is called "Laghar Kóh." Between that mountain and the next ranges to the south-east also consisting of bedded tuffs, there

extends a great talus called " Phoghdan," or "the place of Phogh," from the name of a bush called by that name. The rocks dip at such high angles and the bedding is so obscure amongst these black volcanic beds that it is difficult to tell their true structure. Laghar Kóh seems to be a sharp anticline. In the range south-east of Phoghdan the dip appears to be generally south-east. In addition to the bedded volcanic rocks there are numerous narrow basaltic dykes of much later date. Similar dykes will be mentioned in many other localities cutting through all manner of sedimentary and igneous rocks.

Resting upon these tuffs are flaggy limestones interbedded with shales, or rather slates, and which present brilliant green and red colourations. These brilliant colours are probably due to an admixture of volcanic material, and several instances have already been noticed in which the lower eocene beds are of a tuffaceous nature. Such is, perhaps, the age of these strata, but in the present case they are altered to such an extent as to be transformed into finely lamellar slates. Sections of corals may be discerned in some of the thicker bedded limestones, but no fossils were met with in a sufficient state of preservation to be identified. The Nimik road from Phoghdan follows a rather steep path that rises amongst these rocks. They are shown on the section between the points marked *c*.

The plain of Kharan stands at a much higher level than the desert to the north-west of the ranges; hence, the road after rising to the top of this steep path (where there is a ziárat dedicated to the Pír Sultán) does not descend again, but simply winds about at a nearly constant level amongst the ridges that constitute the range and reaches the Kharan plain at "Shír Ajab ziárat," near the place marked "Arrok" on sheet 22 S. W. Judging by analogy with the previously described sections, all these rocks (*d*) clay-slates and limestones must be tertiary, but they are cleaved and metamorphosed to such an extent that all trace of any fossils has disappeared. The shales are entirely transformed into soft micaceous, silky slates; some indistinct spots occasionally seen in

the limestone bands might be the remains of nummulites. Only in one instance, to be further described, in the Persian province of Sarhad did I come across such an extreme type of metamorphism (page 89). It is only in the limestone ridge bordering the Kharan plain at Shír Ajab Ziárat (*f* in section) that any distinct sections of nummulites can be recognized. This limestone rests upon shales which are not quite so much altered as the slates just described. Beyond this point the rocks are hidden under alluvial deposits. Other low ranges occur between the alluvial plain and Naoróz Khán Kelát. All that can be made out from a distance is that they have a south-east dip, but I did not visit them.

The Parhod Pass.

Continuing further south-west along the strike of the mountains the next pass is the "Parhod Pass," which I did not visit. It is probable that the central ridges still consist of tertiary rocks, but it would seem that the range is bordered on either side by an outcrop of the bedded tuff of the flysch. Along its north-western border the volcanic strata described in the previous sections still continue uninterrupted, while on the opposite side the range called "Chár Kóhan," a tall black ridge, apparently consists of similar rocks so far as could be judged by its appearance from a distance of about three miles. The outcrop is perhaps connected with the band of volcanic strata that forms the range called "Charian" and "Sehchang" further west-south-west, but of this I could not make certain as I did not visit the country south of "Rás Kóh."

The Rás Kóh intrusion.

Still continuing in the same direction we find that the strike of the ranges becomes unsteady. Portions with a south-west or west-south-west strike are irregularly dovetailed into others that lie east-west. It is here that the most conspicuous feature of the range commences, the great plutonic mass, whose highest summit, the "Rás Kóh," rises to a height of 9,899 feet. This great igneous outcrop has the shape of an irregular elongated oval whose length is thirty-eight miles, while the maximum width averages five miles. The general trend of the outcrop is

east-west. The intrusive character of the rock is made clear by the apophyses which it sends into the surrounding rocks and the inclusions of sedimentary rocks all round the margin of the igneous mass. The sedimentary rocks are altered by contact metamorphism, and the intrusive rock itself is of a different character near the boundary, becoming finer grained and less perfectly crystalline.

The minerals present in this rock are orthoclase and oligoclase felspar, augite, hornblende, biotite, magnetite (or ilmenite), sphene and apatite. The two latter minerals are very abundant and conspicuous even to the unaided eye, the apatite often forming beautiful crystals of a pale sea-green colour, which frequently reach a dimension 5 millimetres in diameter. Throughout the enormous area occupied by the plutonic mass the same minerals are found, but their proportion varies greatly from place to place. In the eastern portion of the intrusion the rock contains a considerable proportion of large crystals of orthoclase. Augite is much more plentiful than hornblende, so that the rock should be classed as an augite syenite.

Augite syenite.

Further west the proportion of hornblende increases, while orthoclase is replaced almost entirely by plagioclase felspars, the rock becoming a diorite.

South and south-west of Alam Khán, at the western extremity of the great intrusion where it breaks up into a number of separate dykes, the structure as seen under the microscope is quite porphyritic; and this is the case also with all the specimens collected near the junction of the igneous mass with the sedimentary strata, even where the outcrop is broadest.

In these portions where the outcrop is very broad the sedimentary rocks are altered by contact metamorphism up to a distance of as much as fifty feet from the boundary of the intrusion. On its northern side the intrusive mass comes into contact with ancient volcanic rocks of the flysch period; being igneous rocks themselves they do not show very conspicuously the effects of contact metamorphism. But to the south where the intrusion has found its way through the eocene argillaceous rocks the effects of metamorphism are

very clearly marked. The tertiary rocks here consist principally of shales which, as elsewhere, are affected by regional metamorphism which has converted them into slates; these slates are very well cleaved, but they are soft and friable. In the neighbourhood of the intrusion they become baked into a hard rock.

South of Charsar the syenite is cut through by very curious dykes of hornblende-biotite-porphyry, a yard or two in width.

The syenite or diorite is further remarkable for containing silicate of copper, not in veins but in grains or small masses distributed through the rock, as one of its constituent minerals. The same peculiarity is observed in the Lar Kóh diorite in Persia (page 86). The metal has been occasionally extracted by inhabitants of the neighbourhood.[1]

The Pír Puchi Pass.

The great igneous intrusion terminates in the neighbourhood of the well called "Alam Khán". The range has here attained a considerable width, as much as twenty miles. It is crossed at this place by the best of the passes that lead into the Kharan State, an excellent road called the "Pír Puchi Pass." The general strike of the ridges is here W. S. W., but the local variations are numerous and irregular. The outcrop of ancient volcanic strata which constantly forms the northernmost ridge of the mountains from Tafui westwards can still be recognised in the same position although somewhat dwarfed. But a short distance south of it another outcrop of the same rocks forms the conspicuous black range appropriately called "Siáh Chang" (the "black mountain") and further east "Charian". This outcrop is perhaps the western continuation of the "Chár Kóhan" (page 51).

At the northern entrance of the "Pír Puchi Pass", we find thus two roughly parallel, or rather converging outcrops of flysch strata. The eocene shales and limestones lie between these two, forming an irregular syncline which becomes narrower in a westerly direction.

[1] Prof. Judd has noticed the existence of cupriferous igneous rocks in Scotland (Quart. Journ. Geol. Soc., Vol. XLI, p. 374).

In fact it seems as far as can be judged from a distance, that the two outcrops of volcanic strata coalesce into one, in the neighbourhood of the locality called Kanian; but I have not made sure of this by actual observation. The syncline of tertiary rocks consists principally of slaty shales with some narrow limestone bands containing nummulites. Underlying these nummulitic strata and immediately overlying the bedded tuffs are those same bright coloured shales and flaggy limestones that were already mentioned when describing the Nimik Pass Section (page 50); in the present case they are also highly cleaved.

With the possible exception of the rocks at (*k*) (Fig. 4), which I have not visited, there is nothing but tertiary rocks between the Charian range and the Kharan plain. The Kharan plain here is much lower in altitude than in the case of the sections hitherto described. It has become a broad desert of alluvial "pat" and sand dunes. South of the Charian range the mountains consist of innumerable ranges of slates; the beds are sharply contorted, causing them to dip at very high angles, as is shown in the illustration (Pl. X) of the hill at Zard. We have here an instance of the irregularities mentioned above with respect to the strike: the strata shown in this picture dip 10° E. of N. at 75°, the strike being therefore in this special instance 10° N. of W., while the general trend of the ranges is W. S. W. The shaly beds are everywhere converted into slates, but nummulites are still recognisable in the limestone bands.

A considerable limestone band gives rise to a tall range north of Jalawar. Sections of nummulites are clearly seen upon the weathered surface of the rock (*i* in section, Fig. 4). It is underlaid by sandstones containing volcanic material and by shales which are not cleaved to the same extent as those met with along the main portion of the section. The limestone belongs probably to the Ranikot horizon like the one described in the Shekh Hosein section (page 48). It seems that there is again a limestone at Jalawar, at the edge of the desert plain (*k* in section). It is not only of geological but also historical interest, as it carries an inscription several centuries

old; unfortunately I received this information after leaving the region, and on the only day that I could dispose of, I found the hour so advanced that I returned northwards when within one mile from Jalawar, where the inscription is to be seen.

This inscription (a Mahomedan one), is one of the numerous remains that indicate a previously flourishing condition of this region now absolutely uninhabited except for six weeks during the spring-time when small companies of men with pack animals come and encamp amongst the hills to collect asafœtida. In all the valleys south and south-east of Zard, the walls called "Górband," those remains of terraced fields which I mentioned in a previous chapter, are met with in countless numbers. In another part of the Kharan hills, in the "Nimik Pass," Mahomedan tombs were met with built in exactly the same style as these old walls. I have already referred to these structures (page 37) as showing that the complete dessication of the country as we see it at the present day must be of a very recent date.

Western termination of the Kharan ranges.

West of the Pír Puchi Pass the ranges that we have followed from the neighbourhood of Nushki gradually decrease in height, and about longitude 64° they sink beneath the recent deposits of the desert plain. I have not examined this western termination of the mountains, although there are no doubt many points of interest, for instance, the curiously rectilinear ridge called "Irani Thal Gar". It is quite possible that the folded structure continues beneath the alluvial deposits of the plain surrounding the Hamun-i-Mashkhel, and that the low ranges south-west of the Kóh-i-Sultán are structurally the continuation of the Kharan hills, this time with a N. W. strike. They will be described in a future paragraph.

Conclusion.

Incomplete as they are, the observations made upon the range which has just been described, are sufficient to show that it possesses a very irregular structure. Its northern edge is particularly abrupt and shows nowhere the regular band of Siwaliks which form so conspicuous a feature

along the foot of the range east of Nushki (page 43) and which recur in a similar situation along the Saindak ranges (see page 79). On the other hand Siwaliks were found occupying a valley in the midst of the mountain mass (see *ante*, page 47). The component ridges show many irregularities in strike, and the great syenitic intrusion of Rás Kóh forms an elongated outcrop whose position does not bear much relation to the structure of the surrounding sedimentary rocks. Thus it seems that the structure of the range is very complex, but my observations are not sufficient to unravel its peculiarities.

The next range to the north has received still less attention; but it seems to present at least one very regular feature, it is a constant belt of Siwalik strata along its southern border, everywhere dipping inwards, towards the range. Between this belt of Siwaliks to the north or north-west and the Kharan hills to the south or south-east, there extends a plain having the shape of a very broad flat valley whose width gradually increases in a westerly direction until it joins the Kharan plain and they both merge into the great depressed area of the Hamun-i-Mashkhel.

The Nushki-Dalbandin depression.

In the neighbourhood of Nuskhi this plain is comparatively well watered and accordingly it is somewhat extensively cultivated. But as it gradually broadens to the south-west, it soon becomes one vast desert. Oases are only found in places where a "kárêz" proceeds from the talus of the Kharan ranges; for instance, at Mall where a large area planted with tamarisks gives almost the illusion of a Sind landscape; again at Charsar where there are some brick tombs probably of the seventeenth century whose construction, rough as it may be, denotes a state of the population less degraded than at the present day. There is also a certain amount of irrigation in the neighbourhood of Dalbandin.

A great portion of the plain is covered with sand dunes, even in the immediate proximity of cultivated land, for instance, at Nushki. Where it is not concealed by wind-borne sand, the surface of the

desert consists very largely of the loose gravels called "dasht," or else in the low-lying parts we find those accumulations of dried up silt called "pat" (see *ante*, page 12). Sometimes the "pat" is covered with a saline efflorescence in which case it takes the name of "narpat." A few depressions are occupied by the permanent ponds called "nawar" (see page 13).

Only in very rare instances do inliers of the older rocks rise out of these recent deposits; when they do occur, as at Mall and at Padag, they are not far distant from the main outcrop. This almost complete absence of exposures away from the mountain ranges appears to be a general feature of many Iranian and Central-Asian districts. It has been commented upon by Mr. Blanford as a proof of the enormous thickness attained by the recent formations.[1]

Range extending north of the Nushki-Dalbandin depression.

First part; from Nushki to the Lora Hamun.

In describing the geology of the neighbourhood of Nushki, it was mentioned (page 43) that the southern continuation of the Siwalik hills separates into two branches. The western branch marks the commencement of a long line of similar strata forming the southern border of the low range that runs between the Nushki-Dalbandin depression to the south, and the bed of the Lora to the north. As the greatest part of this range has remained unexamined, it is not possible to tell for certain the nature of the belt of strata north of the Siwaliks. This eastern portion of the range (east of the Lora Hamun) was crossed only once, and then very rapidly in the neighbourhood of "Mékh-i-Rustam," on the day that I visited the curious conical hill bearing that name. At that spot the Siwaliks form numerous parallel ranges very similar in appearance and in composition to those of the Píshín plain. They invariably dip N. by W., as if underlying the older strata north of them, which also dip in the same direction, making it clear that they must be separated from them by a fault or more exactly a thrust-plane. These older

[1] Quart. Journ. Geol. Soc., Vol. XXIX (1873), p. 498.

strata consist of friable shales and sandstones, very much contorted but without any indications of slaty cleavage such as occurs in the Kharan hills. Fossils are found in an excellent state of preservation, but unfortunately I had no time to collect; *nummulites, alveolinas, operculinas, cerithiums* and other fossils of Ranikot age were found. Here also conglomerates of volcanic pebbles were met with, such as have already been noticed in other instances amongst beds of that age (page 46).

Mékh-i-Rustam.

The Mékh-i-Rustam is an igneous intrusion. Owing to the comparatively small dimensions of the plutonic mass, the structure is not a granitic one as in the case of the Rás Kóh syenites, but it is porphyritic, the rock being a felsite porphyry. Being a highly siliceous rock it successfully resists weathering, while its compact nature explains why it has withstood denudation so much better than the friable sandstones and shales that surround it. The curious conical hill rendered so conspicuous by its contrast with the insignificant hills that surround it does not by any means represent the original shape of the intrusion, for up to a distance of one mile north of it, the same rock still appears *in situ*.

Chapar range and its neighbourhood.

Not far from the southern shores of the Lora Hamun stands another conspicuous hill of conical shape, at one time an island before the lake had dried up, probably still so in time of flood. This hill, the Gaukóh, does not consist however of igneous rocks, but of high dipping, in fact vertical limestones. West by south of it the smaller Kóh-i-Gav is similarly constituted, and from there, in a direction a few degrees south of west, a continuous outcrop of the same limestone forms hills gradually increasing in height and culminating in the tall scarped mountain called Masanen Chapar or the "Great Hill." Still further west these rocks again decrease in height forming the Kasanen Chapar or "Small Hill."[1] No fossils were found in this great limestone, save a few indistinct corals. The rock certainly resembles

[1] Since these lines were written, the author has again visited the Chapar hills. The uppermost beds of the Kasanen Chapar limestone contain the *Cardita beaumonti* fauna. The age of the limestone is therefore upper cretaceous.

closely a limestone of "*Cardita beaumonti*" age which will be mentioned further in connection with the Malik Gatt; it also overlies shales of olive-green and other tints also closely resembling the *Cardita beaumonti* shales of Malik Gatt. It is true that at Kán, about one mile north of the Chapar limestone, there occurs a small hill in which fossils were collected indicating an upper cretaceous horizon. Both in this small hill and in the great Chapar range, the strata dip slightly W. of N. at angles varying from 20° to 30°. If the structure is a normal one the strata at Kán must belong to a horizon several thousand feet higher than the Chapar limestone, which therefore might belong to the middle or even lower cretaceous. But as the section is not continuous, the two ridges being separated by an alluvial plain, their relative stratigraphical position must remain doubtful, especially as the Siwalik strata are still there along the southern margin of the folded region, reminding us that the structure is not a simple one (Fig. 5).

North of Dalbandin these Siwaliks form an outcrop several miles wide, no doubt the continuation of the band mentioned first near Nushki and again south of the Mékh-i-Rustam. In the present instance they constantly dip north, or slightly west of north, often at angles of 55° or even more. Their conglomeratic beds frequently contain fragments of the rocks occurring north of them. The petrological characters of the latter rocks show them to be older than the imperfectly indurated Siwaliks. As, however, the dip remains unaltered, it is evident that there occurs here an inverted fault. These older rocks consist of tuffs and ash-beds of the flysch period. Some of the ash-beds assume almost incredibly vivid colours on weathering, and as beds of this nature have largely contributed by their desintegration to provide materials for the formation of the Siwalik strata, this may account for the bright colours exhibited by many of the clays in this latter formation. The flysch strata generally dip 15° W. of N. at high angles, 60° or more, and they are moreover sharply contorted. The next band of rocks to the north, whose strata apparently rest upon those of the flysch, are shales and calcareous sandstones with some conglomerates

of volcanic pebbles, very similar to the Ranikot beds observed near Mékh-i-Rustam. No fossils were observed, but supposing this to be their age, their position relatively to the flysch strata would be normal.

North of these presumably eocene beds there is a plain covered with pebbles beyond which occur the olive-shales and then the great limestone of the Chapar range. If the band of shales and calcareous sandstones be tertiary, and the olive-shales and limestone of the Chapar range cretaceous, it is evident that a thrust-plane again occurs here, for the direction of dip remains unchanged in all these rocks.

The Chapar limestone is about 300 feet thick; it is overlaid by some calcareous flags resembling the strata at Kán, and another alluvial plain extends up to the small hills at the last named locality. Figure 7 shows a more detailed section of these small hills.

Some fossils were collected in the strata composing this small ridge, and Dr. Noetling who kindly examined them pronounced them to be upper cretaceous. The commonest form is a *Cardita* closely allied to *Cardita beaumonti*, in fact a mere variety.

The structure of this small ridge is not everywhere so simple as is shown in Fig. 7, occasionally there occur some very sharp contortions. Whether or not these beds really belong to a higher horizon than the Chapar strata, has already been discussed. It is evident that the entire group of hills has a complex structure, and, since fossils do not occur everywhere, the exact relations of all the strata could only be made out by carefully mapping out each outcrop ; a single traverse cannot give the key either to the stratigraphy of the range nor to the age of the beds.

Siwaliks and recent deposits north-west and west of Dalbandin.

Following the strike of the Siwaliks in a westerly direction beyond Dalbandin, we find that the width of the outcrop still further increases. These strata do not form here those low parallel ridges so characteristic of other regions, but the entire surface of the ground is cut out in a succession of terraces in the manner described in a previous chapter (page 32). The terraces are covered with sub-

recent conglomerates hardened into a compact mass; these gravels are of fluviatile origin, the ground generally having a very gentle slope in the direction of the drainage, but as pointed out in a previous chapter, the very regular differences of level between these recent conglomerates, the lowest being the newest, no doubt represent corresponding differences of level of the water surface in the gradually dwindling lakes.

Throughout the considerable width of the Siwalik outcrop the dip is everywhere northward, often at high angles, the sub-recent gravels resting horizontally upon the denuded edges of the tilted strata. The Siwaliks consist of the same rocks as elsewhere: clays often bright-coloured, loose sandstones, conglomerates. No definite succession can be made out, although it is probable that the clays are generally older, the conglomerates generally newer. The clays are often intersected by a perfect network of veins of gypsum, the mineral occurring both in clear mica-like plates, and in an earthy form. It is often associated with very clear crystals of calcite, which take the shape of obtuse rhombohedra.

Gatt-i-Hamun.

North of these Siwaliks is the Gatt-i-Hamun or "Cliff of the Marsh." It may be regarded as the continuation of the folded band of rocks extending south of the Lora river and through the Chapar range. The cliffs are formed by the scarped face of a thick limestone mass (*c* in Fig. 8). It is underlaid by olive-green shales which are visible up to a certain distance south of the escarpment, being very highly contorted (*a* in Fig. 8). They contain numerous veins of gypsum. The limestones are associated with volcanic tuffs. These rocks greatly resemble those to be described at the "Malik Gatt" (page 63), which are of ***Cardita beaumonti*** age, but in the present instance I did not meet with any distinct fossils.

Hills at Mirui.

The hills in the neighbourhood of Mirui may be looked upon as a further continuation of the same range. They consist of folded strata, greenish-grey shales and calcareous sandstones petrologically identical with those that form the great range east of Nushki (page 41). Just as at Nushki, there

are no fossils or only very indistinct ones, but reasons have been stated for regarding these rocks as tertiary. The mode of disturbance is quite similar to that represented in figure 6, giving rise to the same castellated and ruiniform appearances. The ranges generally trend a few degrees S. of W., but the strike is irregular. Along the north-western border of the hilly tract are a few conglomerates with volcanic pebbles such as were met with near Mékh-i-Rustam in beds of Ranikot age (page 58).

Near the south-eastern edge of the hills, where they border on to the desert, the strata are cut through by dykes of quartz-felsite-porphyry.

The irregularity of the structure at this point is further exemplified in the three hillocks called the Laki hills ("Laka" on the map) south-east of Mirui. Here the strike is W.-N.-W. instead of W.-S.-W., the dip southerly instead of northerly. West and north-west of the hillocks the region separating them from the Mirui hills is entirely covered with recent deposits so that the structural relations of the two groups of hills cannot be made out. To the north, east and south-east of the Laki hills, Siwalik strata are seen. This is the most westerly outcrop of the band of those rocks which we have followed westwards from the neighbourhood of Nushki; beyond this point everything is concealed by recent deposits. Immediately east of the Laki hills, an anticlinal axis runs in an easterly direction through these Siwaliks, showing that they also no longer possess so simple a structure as further east.

The Laki Hills.

As to the Laki hills themselves, they consist of gypsiferous shales and tuffaceous sandstones of bright colour, overlaid by a coralline limestone. All these strata are highly disturbed and crushed. Fossils are plentiful but distorted and badly preserved owing to the shattered condition of the matrix. Dr. Noetling who kindly examined them assigned to them a Ranikot age. The commonest form is *Astrocœnia blanfordi*, Duncan, a typical coral of the Ranikot in Sind.[1]

[1] Palæontologia Indica, Series XIV, Vol. I, Part 1, p. 41.

North-west of the Mirui group of hills there is a curious feature called Malik Gatt or Gatt-i-Barot, from the name of a neighbouring spring in the midst of a deserted plantation of date-palms. It is an elongated tabular hill consisting of absolutely horizontal strata. The longest direction of the hill is in a S. W. direction. The horizontality of its strata is quite exceptional and local, for similar strata that outcrop north-west and south-east all dip at high angles to the north-west.

Malik Gatt.

The hill (Pl. V) has a terraced appearance due to two important limestone bands. The lowermost beds (1 in Fig. 2) are soft dark grey shales full of veins of gypsum. Above these are coarse-grained beds, sometimes almost conglomeratic, made up of volcanic fragments, and full of oyster shells (2). Next comes a limestone (3), of brown or buff colour, with black fossils. The uppermost beds of this limestone are full of volcanic material. The shales (4) which are often of greenish and purplish tinge are frequently interbedded with conglomeratic bands resembling those that form the band (3). Lastly they are overlaid by the coralline limestone (5). Petrologically this limestone is not unlike the coralline limestone of Ranikot age of the Laki hills ; but the fossils show that it belongs to a different horizon, being upper cretaceous. Dr. Noetling recognised several forms characteristic of that horizon ; the variety of *Cardita beaumonti* which I mentioned as occurring at Kán (page 60) is also found here.

I have stated that the horizontality of the beds constituting the Malik Gatt is exceptional as it is surrounded by high-dipping strata. In fact the north-eastern extremity of the tabular hill itself exhibits some disturbance. As already stated, both north-west and south-east of the hill, the dip is north-west. Throughout the plain south-east of the Malik Gatt, separating it from the Mirui ranges, small outcrops of a tuffaceous sandstone are frequently visible notwithstanding the presence of recent pebbly alluvium. As the dip is always in the same direction, it would seem that the rocks of the Malik Gatt belong to a horizon higher than those of the Mirui hills ; but in the

former case the rocks are cretaceous, in the latter they are probably tertiary. The case is analogous to that of the Chapar range and the strata south of it (page 59), and here also the probable explanation is a fault or thrust-plane.

Small hills south-east of Cháh-i-Sundan.

There are a few outcrops of rocks west of the Malik Gatt, the most westerly ones forming some small hills south-east of Cháh-i-Sundan. They consist of strata very similar to those that form the Malik Gatt; shales and limestones interbedded with sandstones and conglomerates formed of volcanic fragments. The dip here is not in the same direction, however, as near the Malik Gatt; it is 10° west of south at low angles from 10° to 15°.

This is the most westerly hill which can be regarded as the continuation of the more northern of the two ranges which we have followed from the neighbourhood of Nushki. West of this point everything is hidden by recent deposits for a distance of sixty miles when another set of low parallel ranges rises out of the alluvium south-west of the Kóh-i-Sultán, this time with a west-north-west strike. It has already been mentioned (page 55) that they may represent the continuation of the Kharan hills, but it is just as probable that they are connected with the range last described. In fact it is quite possible that beneath the recent deposits of the great sandy desert north of the Hamun-i-Mashkhel, the flexures of both ranges become broader and shallower and finally coalesce into one broad folded area south-west of the Kóh-i-Sultán.

Hills of the Balúch-Afghán Boundary.

Let us take it for granted that the folded strata do really continue beneath the recent alluvium between these last hillocks of Cháh-i-Sundan and the low ridges south-west of the Kóh-i-Sultán, in accordance with the above supposition. We would then have an uninterrupted band of folded strata extending from Nushki to the

east up to Kóh-i-Malik-Siáh on the west along an are of a circle concave towards the north. South of it, as far as the Mekran coast, the folded ranges are closely packed in parallel series with occasionally a longitudinal desert plain extending between two ranges that are exceptionally far apart. But north of the concave side of the arc the desert plain extends uninterrupted up to the Helmand river (and even beyond). Some hills do occur nevertheless, and even rise to considerable altitudes along the Balúch-Afghán boundary; but their structure differs from that of the folded ranges to the south; we find no more any regularity in the strike, and the dips are often quite shallow. The hills belong to the second regional type mentioned at the beginning of these notes (see *ante*, page 7). It would be perhaps more logical to describe them after completing the description of the folded ranges, but as the order followed in these notes is rather geographical than geological, they will be considered now, as they conveniently bridge over the great interval covered by recent deposits that lie further south between Cháh-i-Sundan and the ranges south-west of the Kóh-i-Sultán.

Islands in the Lora-Hamun.

We shall proceed with the description in an east-to-west direction. Several rocky islands rise from the sun-cracked mud of the Lora-Hamun. One of these is Gaukóh already mentioned as forming part of the Chapar limestone outcrop (page 58). A little further north are some small conical hills, "Khalbut" and "Kaftáni". While the Gaukóh consists of almost vertical limestones, these small hills are made of gently dipping tuffs and lavas. They are dark purple in colour and belong to the flysch period. On the hill called Kaftáni are the remains of terraces of pale-yellow silt similar to the material forming the bed of the Hamun; they have been mentioned in a previous chapter (page 33).

Hills between Chágai and Butak.

Between Chágai to the east and Butak to the west is an important mass of mountains many summits of which exceed 7,000 feet in height, covering an area one hundred miles long from east to west, and fifty miles broad

from north to south. The rocks constituting these mountains are extremely interesting as there is reason to think that they form part of one of the great volcanic centres of the flysch period. Unfortunately my observations of this interesting district are very scanty; I was never encamped amongst the mountains, but did nothing more than touch them at a few points. The following notes contain an account of the facts observed.

Hills north-west of Chágai.

I followed the road that leads from Chágai to "Balanosh Ziárat," a spot much resorted to by pilgrims. The rocks met with are enumerated on the section, figure 12. The limestone (1) and possibly the highly metamorphosed rock (2) and (3) are the only sedimentary rocks. In all the sections hitherto described the volcanic products of the flysch period were in the shape of strata, principally tuffs. But here we find a considerable development of massive igneous rocks of basic character, evidently intrusive. There is great evidence of solfataric action which has given rise to secondary minerals in great profusion, such as in the rock $\frac{13}{953}$ so rich in epidote as to be practically an epidote-rock. These great intrusive masses consist of fine-grained rocks of volcanic appearance and they may represent the deep-seated portions of some of the great volcanic apparels of the flysch period. Most of the volcanic products are submarine, but in some cases the ejected materials must have accumulated to a sufficient height to form islands as is shown by the waterworn pebbles observed in some of the shallow-water deposits of the Ranikot age. The augite-bearing gabbros and dolerites, in the present instance, are accompanied by intrusions of a more acid composition particularly rich in micrographic quartz. Their microscopic structure is porphyritic or felsitic, but coarser grained rocks will be mentioned from other localities of the same group of hills, always presenting the same exceptional composition of quartz and plagioclase felspar and with a typical tendency to a graphic or micropegmatitic structure. The age of these micropegmatitic quartz-diorites will be discussed further on (page 68).

Rocks east and south-east of Pushtiwan.

From Balanosh Ziárat westwards I did not examine the hills for about fifty miles. Judging from fragments carried down by rivers, they seem to consist principally of basic and acid igneous rocks just as near Chágai. When encamped at Mirui I visited them in the neighbourhood of "Pushtiwan." They are separated from the Mirui hills by a pebble-strewn plain in the midst of which there rise some sedimentary strata with a southerly dip, south of Tahlab Well. East of Tahlab Well there outcrops some diorite, north of which we find great masses of basic rocks apparently intrusive, and again north of this a considerable outcrop of quartz-diorite. This rock which, in the field especially, has quite a granitic appearance is very rich in quartz and does not seem to contain any orthoclase. The constituent minerals are plagioclase, quartz, hornblende, biotite and magnetite. The appearance of the rock varies greatly within short distances owing to the varying proportions of the above minerals. One variety which in the field has the appearance of an aplite consists of nothing but quartz and plagioclase felspar. When microscopic sections of the rock are examined it is found that the structure is seldom truly granitic, but has everywhere a most distinct tendency towards that of a granophyre. The coarseness of grain varies as much as the composition of the rock, and it is a fact worthy of notice that at its junction with the basic rocks, the diorite becomes a felsite consisting of porphyritic crystals of quartz and of felspar distributed through a minutely microcrystalline groundmass. In this special case therefore the acid rock seems newer than the basic one, for the basic one had already cooled down when the dioritic intrusion took place. Thus, judging from this one fact alone, the quartz-diorite may be regarded as one of those intrusions which are at the oldest of upper eocene age, as was pointed out in a previous chapter (page 23) just like the Rás Kóh intrusion and others. Yet there are circumstances which make them appear much more directly connected with the volcanic products of the flysch period in this present instance. One of them is the presence of micropegmatite not only in small masses with porphyritic structure

as at Chágai, but in much larger outcrops where the structure becomes granitic as in the present instance at Pushtiwan or in the still more granitic looking rocks of Malik Naro to be mentioned hereafter. It is true that large as they are these outcrops are small compared with the enormous mass of Rás Kóh and that this might account for their less perfectly granitic structure. The Rás Kóh rocks do not contain any quartz, therefore they cannot show any micropegmatite. But at Bibi Mah in Persia there is an intrusion comparable in size to the Rás Kóh mass and similar to it in age and in its mode of occurrence, and differing in composition, as it is like the rocks at present under consideration a quartz-diorite very rich in silica. The main mass of the intrusion has a granitic structure; but near its junction with the tertiary sediments and in the narrow dykes that surround the main mass the structure becomes porphyritic, with however only a slight tendency to the formation of micropegmatite. At Bibi Mah as at Rás Kóh the intrusive rocks are acid and intermediate. But in the case at present under consideration there are also large basic intrusions, and it has been noticed by several observers that some connection seems to exist between basic intrusions and micropegmatite. If, however, that connection does exist in the present case, the acid rocks must belong to the age of the flysch to which the basic intrusions most probably belong, and they must be older therefore than the igneous masses, upper eocene at the earliest, that form Rás Kóh and Bibi Mah.

The great basic intrusions of Chágai, Pushtiwan, etc., I have thus regarded as the deep-seated portions of a volcanic centre of the flysch period. The products ejected from volcanoes of that system are often basic; but acid eruptions were also abundant. Thus the acid intrusions associated with the basic ones might themselves be connected with volcanic activity: the deep-seated portions of the acid eruptions must exist somewhere making it perfectly intelligible that plutonic acid rocks may exist both of the age of the flysch and also of later tertiary age. But the survey of all this region has not advanced far enough as yet to solve these problems.

At Pushtiwan, as in many other instances, the question is still further complicated by the presence of basaltic dykes that cut through both the acid and basic rock and are of later date than either. Their intrusion has been accompanied by solfataric action transforming their porphyritic felspars into a mass of finely granular calcite, and the same action has extended for a distance of several yards into the surrounding rocks; this is especially well shown in the specimens from the Malik Naro, $\frac{13}{975}$, $\frac{13}{979}$.

Malik Naro.

The peak called Malik Naro occurs near the western margin of the hills at present under consideration. It rises to a height of 7,915 feet. The peak itself and many of the hills to the south consist of quartz-diorites quite similar to those of Pushtiwan. The acid rock comes into contact with basic ones which are probably also intrusive: these basic rocks contain hornblende, but their structure is that of an augite-bearing rock, the hornblende being of the nature of uralite. Later basic dykes traverse both kinds of rock just as at Pushtiwan.

Butak and east of Butak.

South of the granitic intrusion of Malik Naro, the flysch formation is again represented by bedded volcanic rocks whose considerable thickness indicates proximity to a volcanic centre. At Butak itself they are interbedded with limestones to which an admixture of volcanic ash frequently communicates brilliant hues and a porcellanic appearance. Some of these limestones contain fossils, apparently lower eocene or upper cretaceous, which are difficult to separate from the matrix (spec. $\frac{14}{168}$). Here again the proximity of the volcanic vents is indicated by the frequent occurrence of volcanic "lapilli" side by side with the fossil shells. There are also a great many intrusive sills of basalt and dolerite; it is very difficult to decide whether these also belong to the same volcanic system, or whether they are related to the much newer set of basaltic intrusions which everywhere inject all the rocks with the exception of the Siwaliks.

The dips observed amongst these strata are very low, the structure being quite different from that of the highly folded ranges previously described. The structure of the hills shows nothing but

gentle undulations without any leading direction of strike. South of the Malik Naro intrusion, dips were observed 30° E. of S., at Butak itself 25° E. of N. and 40° E. of N. In the latter case the rocks are tilted at a high angle, but not otherwise crushed or disturbed.

East of Butak and north of Jhuli, horizontal terraces of sub-recent travertine are spread over the slopes of the hills formed by the gently dipping flysch strata. They will be mentioned again in connection with the recent volcanoes.

These calcareous terraces rest partly upon the flysch strata, and partly upon an intrusion of granophyre (spec. $\frac{13}{981}$), of similar composition to the coarser-grained micropegmatitic diorites of Malik Naro and Pushtiwan, but less perfectly crystalline, no doubt owing to the smaller size of the intrusion. At its junction with the stratified rock it assumes quite the appearance of an eurite.

Manzil.

West of the Malik Naro and of Butak there is a sudden drop in the altitude of the mountains. From there up to the great mass of Kóh-i-Sultán, the hills are low and scattered at intervals, leaving a broad gap through which the north wind sweeps with furious violence during the greatest part of the year, burying everything beneath an ocean of sand dunes. At Butak itself the wind is so violent that the surface of the rocks is everywhere sculptured in the most curious manner by the sand grains borne by the hurricane, while further west, all about Manzil, the small rocky hills are half buried beneath the accumulated sand. These hills cause the wind to form eddies and all the valleys, whatever their shape and orientation, are gradually becoming choked with sand.

The rock, wherever it appears, consists of the same volcanic rocks of the flysch period. There is a good exposure at Manzil where the irregularity of structure is again exemplified by the direction of dip 30° W. of N., quite different from the orientation at Butak.

East of Manzil is a large igneous intrusion forming the hill called Manzilgarh; it consists of fine-grained biotite-granite (spec. $\frac{13}{982}$, $\frac{13}{983}$). It is traversed by narrow dykes of basalt (spec. $\frac{13}{984}$).

Amír-Cháh.

Between Manzil and the Kóh-i-Sultán almost everything is hidden under recent alluvium and sand dunes. The small hills called "Dholi," south of Manzil, and some hills beyond the eastern extremity of the Kóh-i-Sultán, seem to consist of flysch volcanic rocks, but I have seen them only from a distance. Recent alluvium mostly derived from the Kóh-i-Sultán itself and sand dunes conceal also all the rocks north of that mountain. West of the Kóh-i-Sultán, however, and in the neighbourhood of Amír-Cháh, the older rocks once more reappear from beneath the covering of modern volcanic accumulations.

Here again they consist almost entirely of volcanic strata, tuffs and ash-beds of the flysch period. The strike is generally east-west. Intrusions of quartz-diorite and quartz-porphyry are frequent; there is even an inlier of these rocks amidst the recent deposits of the Kóh-i-Sultán to the south of Gam-i-Cháh. Similar formations evidently underlie the cones of the modern volcano, for the explosions have forced their way through granitic masses as is shown by the nature of the boulders contained in some of the agglomerates. While at Shekh Hosein (page 48) and elsewhere we found volcanic products of the flysch period distinctly interbedded with tertiary strata, in the present instance their cretaceous age is no less clear, showing that the period of volcanic activity overlaps the end of the secondary and beginning of the tertiary. At Amír-Cháh itself there is a ridge of hippuritic limestone cut through by a gorge which has been mentioned already with reference to physical geography (page 38). The hippuritic limestone is both overlaid and underlaid by flysch strata. A fragment of hippuritic limestone also forms the conspicuous peak called "Sor Kóh," west of the recent volcano Damodim. The Sor Kóh limestone rests conformably upon a great accumulation of volcanic strata. It is much thicker than the Amír-Cháh limestone which it, however, greatly resembles; perhaps it is the same rock, the difference of thickness being due to local variations; the structure would then be as represented on section, Fig

10. All these rocks are profusely injected with basaltic dykes and sills, it being often difficult to decide whether the latter are intrusive or truly interbedded, and to what period they belong. Quite close

Sam Kóh.

to the Afghán boundary, to the N. W. of Amír-Cháh, the low flat-topped hill called Sam Kóh also consists of black tuffs, here quite horizontal.[1]

Tozgi and neighbourhood of Tozgi.

At Tozgi, south-west of Amír-Cháh, the orientation of the structural features has again changed. The dip is 25° to 30° W. of N. at angles varying from 25° to 30°. The strata form a succession of monoclinal ranges, consisting principally of bedded tuffs and breccias together with intrusive sills (Fig. 1). The breccias contain large boulders of hippuritic limestone. In a south-west direction, the ranges sink rapidly beneath recent deposits; the last hillocks visible at the edge of the alluvial plain dip in quite a different direction, 40° W. of S. They probably belong already to the region of regular folds further south, for their strike is the same.

At Tozgi the strata are particularly free from any violent disturbance; not only is there no cleavage, but the rocks are remarkably free from jointing, which permits the collecting of exceptionally fine specimens. At the same time they exhibit an instance of the difficulty experienced in interpreting the relative ages of some of the igneous rocks. In the field all the rocks have at first sight the appearance of a conformable series of strata; but while on the one hand *c* is an andesitic lava, and *g* a quartz-trachytic breccia, on the other hand the rock *a* appears under the microscope as a finely crystalline porphyritic eurite, *d* is a granophyric diorite-porphyry or dolerite, and *h* an augite-diorite-porphyry. The latter rock exhibits a basaltiform jointing; the field evidence as to its intrusive nature is not quite conclusive: it does seem that it is not quite parallel to the stratification, but as the strata are slightly affected

[1] Judging from photographs taken by Mr. Tate, the historical Kóh-i-Khwája in Seistán has a very similar appearance. It is also flat-topped, and consists no doubt of horizontal strata. Like the Sam Kóh, it illustrates the absence of folding which has been mentioned above (page 7) as characteristic of the low-lying areas.

by faulting, the exact relations of the rocks are somewhat obscured. It is, however, very similar in all respects to other columnar rocks which will be mentioned hereafter (pages 76, 77), and whose intrusive character is well established, but whose exact age is doubtful, as there exists some uncertainty as to whether they are intrusive sills contemporaneous with the flysch eruptions, or whether they are related to the much later granitic and dioritic intrusions which are probably of upper eocene age. The granophyric micro-diorite *d* is petrologically very similar to one of the most typical of these columnar rocks. The eurite *α* on the other hand resembles the narrower dykes and the edges of many of the large intrusions of the later period. It would seem, therefore, logical to look upon all the intrusive sills of the Tozgi section as belonging to the same later system. At the same time, the presence of a great mass of bedded volcanic products makes it necessary to consider whether the intrusions might belong to the same igneous series. The breccia $\frac{14}{213}$ has characters relating it to a quartz-trachyte; the lava *c* is a more basic andesite, while the tuffs consist of fragments of many varieties of acid and basic rocks. Thus the petrological characters of the eruptive products are not sufficiently uniform to be taken as an argument in favour of any relation between the intrusive and the eruptive rocks. The question is far too complicated to be unravelled by means of the observations made during the short time that I was able to devote to a study of the field relations of the rocks.

Travertine terraces.

At Tozgi there are terraces of travertine of the same nature as south of Jhuli (page 70).

Kóh-i-Humai.

Kóh-i-Humai (called Kóh-i-Rezai on the map) to the north of Tozgi consists of great masses of hippuritic limestone. Here the strike is almost due north. The massive limestone, not less than 300 feet thick, rests upon shales, flaggy limestones, calcareous shales, arenaceous shales, arenaceous limestones, all these strata frequently containing volcanic material (spec. $\frac{14}{217}$) (see section, Fig. 9). At *d*, is another of the columnar rocks of doubtful nature similar to the rock *h* at Tozgi. The

much later basaltic dykes mentioned in so many localities are here very conspicuous.

West of Kóh-i-Humai, all round the modern volcano Kóh-i-Dalil, the older rocks consist of flysch and limestones probably cretaceous. The strata are nearly or quite horizontal giving rise to flat-topped hills.

Road from Amír-Cháh to Saindak.

From Amír-Cháh to Saindak there extends a distance of fifty-five miles without any drinkable water. Owing to this circumstance the road was marched across rapidly and observations are scanty. The difficulties of the march are further increased by the enormous accumulations of sand. Some of the sand hills are of stupendous magnitude exhibiting great unbroken slopes 200 or 300 feet high. In such extreme cases it is probable that ranges of hills are buried beneath.

Wherever the rock is visible it consists of flysch strata with their associated limestones. The dips are moderate; sometimes the strata are horizontal as in the flat-topped hills north of Kóh-i-Dalil. These hills are surrounded by large recent deposits of travertine.

East of the locality called "Zeh," acid igneous intrusions become very numerous, varying in size from small dykes to considerable hill masses like the Drana Kóh. The latter intrusion consists of quartz-diorite through which there run basaltic dykes which have given rise to some solfataric alteration. Parallel with the basalt dykes are small veins containing chrysocolla.

Drana Kóh.

Garuk-i-Gori, in the desert north-east of Saindak, is a ridge of high dipping limestones. I have not visited it, but judging from Mr. Tate's description it is probably hippuritic limestone.

Folded ranges south-west of the Kóh-i-Sultán.

We will now return once more to the region of regular parallel ridges which we left since Cháh-i-Sundan (page 64). It was mentioned there that west of that point the ridges of that structure,

if they exist, are hidden under recent deposits for a distance of sixty miles, when ridges of similar nature are again met with in the country south-west of the Kóh-i-Sultán. Some of the rocks at Tozgi, mentioned on page 72, probably belong to the northern margin of this folded region. Regular high dips are very clearly visible even from a distance in ranges that rise some fifteen miles south of Tozgi. They seem to consist of flysch strata, but I did not visit them.

I visited the ranges further west when marching from Mirjawa to Tozgi. The path follows a waterless and rainless tract. Most of the distance had to be travelled through in two days, which left little opportunity for geological observation. The whole region is occupied by low undulating ranges absolutely destitute of any covering of soil or sand, or alluvium, or boulders, or of any vegetation whatsoever. It is impossible to describe the dreary desolation of such a scene. The dips are generally low, northerly dips somewhat more frequent than southerly ones. The usual strike is 60° to 45° W. of N., though occasionally there are portions met with where the strike is east-west. Almost all the rocks are lavas or tuffs (spec. $\frac{14}{199}$), often very coarse-grained. At one place there is a most extraordinary isolated peak of thick-bedded limestone whose relation to the associated tuffs is not clear (spec. $\frac{14}{128}$). At a certain distance to the west-south-west of the Kóh-i-Dalil, there are coarse conglomerates, loose sandstones with bands and veins of gypsum associated with coloured clays, no doubt Siwalik strata.

About seven miles from Kóh-i-Dalil, in a west-south-west direction, there rises a very curious intrusive boss of diorite-porphyry, consisting of felspar, augite, hornblende, and magnetite, and an isotropic mineral curiously intergrown with the felspar, probably sodalite. In the same neighbourhood there occur some augite-andesites and olivine-basalts whose field relations I had not time to decipher. They appear to exhibit a certain amount of disturbance, but all their minerals, even the olivines, are remarkably fresh. Perhaps, like the peculiar rocks alluded to on page 30, these lavas as well as the porphyritic intrusion, may belong to a volcanic series of Siwalik age.

Neighbourhood of Mukak.

Mukak, a spring to the east-north-east of Mirjawa, lies amongst the continuation of the above described ranges. The ranges have now gained considerably in altitude, and the degree of disturbance has also greatly increased. Cleavage has distinctly set in. The greater height of the ranges favours the production of rain; hence the rocks in the longitudinal valleys between the principal ridges are once more concealed by accumulations of coarse alluvium.

The section (Fig. 14) shows the principal points to be noticed in the neighbourhood of Mukak. South-west of the point (*a*) there are a few hillocks forming parallel ranges, all of them consisting of the ash-beds, shales, etc., of the flysch series. Mukak káréz is in a shallow syncline; then we find next an anticline. At (*b*) the amount of dip is about 10°; cleavage is distinctly seen. Further on comes a "dasht" plain with low ranges; at the point (*c*) the dip is about 40° E. of N. at 40°, the rocks still belonging to the same varieties. The cleavage is still well pronounced, the cleavage planes nearly vertical. The tall range at (*d*) consists of the same columnar basic rocks already mentioned at Tozgi and elsewhere (page 73). Here the junction of the columnar rock with the underlying sediments is exposed uninterruptedly for considerable distances. The igneous rock rests upon flaggy limestones and shales of a kind very common amongst the flysch series. In immediate contact with the igneous rock there is a band of a greenish colour and of a texture resembling that of porcellanite, probably the effect of contact metamorphism; it is not, however, more than one inch in thickness, showing that whether the igneous rock be intrusive or truly interbedded, its metamorphic action has been very slight. Nowhere could the igneous rock be seen cutting across the bedding; the junction is absolutely sharp, the igneous rock remaining very coarse-grained up to the actual junction.

Beyond the point (*d*) comes another plain of "dasht"; then more ranges appear; at (*e*) there is a cliff formed by a thick band of

volcanic breccia, similar in nature to those of Saindak and Siáh Kóh (see pages 79, 80).

At the point (*e*) and beyond it, the cleavage is much less marked than in the more south-western portion of the section. At (*f*) there are some contortions, and at (*g*) there is again a very tall range formed of the same columnar igneous rock as at (*d*). Its enormous thickness quite dispels any doubt as to the possibility of its being a lava-flow. It is clearly an intrusion and from this it appears very probable that the other columnar rocks of similar appearance are all intrusive. In the present instance the rock is remarkable for the large amount of micropegmatite which it contains, but it is more basic than the granophyres of the Afghán boundary mentioned above (page 66).

Beyond the range (*g*) is a plain entirely covered with "dasht", with the exception of some very small ranges only the crests of which show above the superficial formation; they are perhaps the continuation of some of the tertiary ranges of Saindak. Beyond them rises the Amalaf range which is the continuation of the north-eastern range of Saindak.

Mirjawa.

South-west of the ranges just described there is a great plain covered with recent deposits called the "Dasht-i-Tahlab". It separates the ranges hitherto described from other ridges running with a parallel strike and bearing successively from south-east to north-west the names of Kóh-i-Tahlab and Kóh-i-Rihi. Another longitudinal plain occupied by a somewhat important river which bears the name of Tahlab river in its lower course and Mirjawa river in its upper portion further separates the Kóh-i-Rihi and Kóh-i-Tahlab from other ranges to the south-west. The width of the Dasht-i-Tahlab gradually decreases in a north-western direction, so that the ranges that border it coalesce into a belt of parallel ridges which occupy a tract as much as twenty miles wide between Mirjawa and Amalaf. The alluvial plain of the Tahlab or Mirjawa river still continues in a north-west direction up to a certain distance

beyond Mirjawa, so that the belt of parallel ranges still lies between two depressions, that of the Mirjawa plain to the south-west and of the great desert to the north-east. In its structure this compound range affords a good instance of the manner in which the folded strata constituting the hilly region have been forced over the low-lying plain on either side: along either margin of the range the dip is inwards, away from the plain, being north-east along the south-west margin, south-west along the north-east margin. I have not travelled right across the folded region at any point, but observations made near Mirjawa and those made all around Saindak are sufficient to give an idea of the main structural peculiarities.

Symmetrical structure of ranges.

When describing the neighbourhood of Mukak (see *ante*, page 76), it was noticed that as the ranges gain in height, the amount of disturbance also increases. North of Mirjawa the degree of disturbance becomes still further marked, slaty cleavage is everywhere present. The strata are extremely disturbed; there are many local variations both of strike and of dip; the direction of dip varies from north to north-west at angles of 55° to 70°. But there are many minor disturbances, sharp folds and overfolds and small thrust-planes, all indicating a movement of the rock masses in a south-westerly direction towards the Mirjawa plain. The strike of the cleavage planes is far more regular, about 35° N. of W.; the dip of the cleavage planes is inwards, away from the plain at very high angles of 65° and more, sometimes quite vertical. The cleavage runs quite independently of the bedding.

Owing to such a degree of disturbance it is difficult to make sure of the order of succession in the rocks: they include many of the varieties usually found in the flysch series, limestone and calcareous sandstones full of volcanic material, shales and an extraordinary abundance of very flaggy (and in the present instance slaty) limestones and calcareous shales of the brightest hues, such as red, yellow, mauve, white, pink, purple, green. There are several conspicuous outcrops of the columnar rock (Pl. XI) which it was difficult

in the field to decide whether it is a lava or an intrusive sill (pages 76, 77). Microscopic examination reveals a structure which is not consistent with that of a lava-flow. But the age of these sills remains doubtful, and the extreme disturbance which prevails in the present instance does not help towards a solution of the problem.

Saindak.

If now we proceed to the north-eastern margin of the range bordering on the desert that surrounds the Gaud-i-Zirreh depression, we find that the rocks again dip inwards, therefore in this case south-west. The section (Fig. 17) runs a short distance north-west of the mountain called Saindak Kóh. At the extreme margin of the mountainous district are some Siwalik strata (*a*) much concealed by the talus derived from the tall ranges of older rocks. These tall ranges consist of tuffs and ash-beds (*b*); as in many other localities they are cut through by basaltic dykes of a much later date, while there occur also fissures which have afforded a passage to mineral vapours that have decomposed the rock into brilliantly coloured ochres. These tuffs and ash-beds belong to the flysch system, they have a south-west underlie and are overlaid by volcanic conglomerates containing boulders of such a large size that they must indicate the proximity of an ancient volcanic centre.

The uppermost beds of this conglomerate are overlaid by some strata of coarse calcareous volcanic breccias of a bright red colour. Then after a few feet of green shales, the next overlying rock is nummulitic limestone (*d*) in which we find *nummulites* side by side with volcanic pebbles. This point occurs a short distance north of the Saindak spring which is situated in the middle of a syncline of tertiary rock. These tertiary rocks consist of shales, sandstones and limestones and all the fossils, even those from the strata resting immediately upon the volcanic agglomerates are typical Khirthar forms. As the contact appears perfectly conformable, this is an indication that in some localities the volcanic eruptions of the flysch system continued up to a late horizon of the eocene.

South of the Saindak spring, the tertiary strata dip north-east, forming the south-western branch of the syncline. A thick-bedded

limestone forming a conspicuous ridge underlies a richly fossiliferous nummulitic limestone and immediately overlies the volcanic conglomerates (*g*), which present generally the same characters as in the north-eastern branch of the syncline. Continuing the section in a south-west direction, we find that beneath a considerable thickness of these agglomerates is a thick series of tuffs and ash-beds (*h*), associated with shales, sandstones and limestones that often contain a large proportion of volcanic material. All these rocks assume brilliant tints on the weathered surface. A great thickness of these rocks is travelled through in a south-west direction up to the axis of an anticline. South-west of the anticline the section ascends again and the same series of rocks are met with until the agglomerates re-appear again in the Siáh Kóh; they do not seem to be so extremely coarse as further north, being probably further distant from the original volcanic centre. The structure of the Siáh Kóh is that of a syncline which appears to widen out in a south-east direction where there appears to be, so far as can be judged from a distance, another outcrop of eocene strata similar to those of Saindak.

South-west of the Siáh Kóh is again another anticline. After crossing the axis of the anticline, the rocks begin to show signs of great compression; jointing sets in, which soon amounts to distinct cleavage, the planes of the slaty-cleavage dipping south-west at a high angle (*j*). These features become more and more pronounced up to a point where a very clearly exposed overthrust (see Fig. 19)[1] brings a series of rocks of quite a different aspect (*k*). They are once more the same green shales and calcareous sandstones which were met with in the great ranges east of Nushki (page 41) as well as at Mirui (page 61), and elsewhere, and whose exact stratigraphic position remains doubtful on account of the absence of fossils. They are not similar to the Khirthar strata of Saindak, and it seems that the Ranikot horizon is here entirely occupied by volcanic strata. Perhaps they do represent the horizon occupied by the coarse agglomer-

[1] The thrust-planes in the Saindak ranges are very similar in appearance to those represented by Mr. Oldham in Rec. Geol. Surv. Ind., Vol. XXV, p. 28.

ates of Saindak as such a coarse rock could only be of local development. Or else the conformity of the Khirthar strata of Saindak with respect to the underlying volcanic rocks may be apparent more than real. Although there is no apparent uncomformity, yet it is just possible that a break does exist. I have mentioned the occurrence, at various horizons, of conglomerates consisting of waterworn volcanic pebbles which show that the products of eruptions had been piled up to a sufficient height to form volcanic islands rising out of the sea in which all these strata were being deposited. The volcanic conglomerates of Saindak might represent such a local accumulation, and this would account for the absence of some of the Ranikot strata. The strata (*k*) might represent then the portion of the Ranikot missing at Saindak. At Robát (page 85) the Ranikot strata do present a great resemblance to these rocks. A careful search for fossils in the strata underlying the volcanic conglomerates of Saindak would probably settle the question.

If I had seen the junction of these rocks with the flysch strata that border the Mirjawa plain (*l*), some definite indication might have been found to discover their age; but I did not reach that point when examining the hills round the camp at Saindak, while the outcrop could not be traced either from Mirjawa. The south-western extremity of the section (Fig. 17) shows the features observed in the neighbourhood of Mirjawa. As the nature of the rocks and their structure do not vary much in the direction of the strike, it probably gives a fair idea of what would appear if the section had been completed along one line. With reference to the remarkable circumstance of the rocks dipping inwards along either margin of the range, it will be noticed that the south-west dipping features extend much further from the north-east margin than the north-east dipping structures do from the south-west margin. The structure is not absolutely symmetrical: the movement in a north-east direction towards the greater and deeper depression of the Gaud-i-Zirreh lake has been greater than the south-westward movement towards the smaller and less pronounced depression of the Mirjawa plain.

Saindak Kóh.

The very distinct instance of a thrust-plane just mentioned will help to understand a very curious feature which I have omitted to mention so far; this is the Saindak Kóh, a mountain that rises to the east of Saindak spring. The lower portion of the hill consists of the tertiary rocks that were mentioned as forming a syncline; owing to this structure the strata (mostly shales) of the Saindak Kóh belong to the highest eocene horizon since they lie in the axis of the syncline over beds whose fossils present affinities with the Nari fauna. The tertiary shales are capped by a great mass of volcanic agglomerates and tuffs similar to those that underlie the nummulitic strata. The junction of this cap of agglomerates and of the tertiary shales is very sharply defined and abrupt; it is not parallel with the planes of stratification of the shales which are very greatly crushed at the junction. These agglomerates are so similar to those normally underlying the tertiary sediments that they must be regarded in all probability as the same rock, and, considering the very distinct evidence of a thrust-plane in the section above described, the same explanation must be resorted to in order to account for their abnormal situation in the present case. (See Fig. 15.)

Here again we find as in so many other instances narrow dykes of basalt. They run uninterrupted across the great thrust-plane, indicating that they are much later in date than the earth-movements which gave the rocks their present structure and situation.

There are also veins of carbonate and sulphate of lime which become metalliferous when they enter the abnormally situated agglomerate. The ores which they contain are galena together with small quantities of azurite and malachite. These minerals occur very scantily although the lead is occasionally extracted.

Khirthar rocks at Saindak.

This locality is further interesting as the one where the highest horizon was recognised amongst the marine tertiary. Strata of Khirthar age were met with at Tafui (page 47), but in the present case the series appears to ascend up to the base of the Nari or uppermost eocene.

The section (Fig. 11) shows the succession of strata from which the fossils were obtained. The thick-bedded limestone that rests immediately upon the agglomerates is unfossiliferous, but in the more thinly bedded rock that rests upon it a number of Khirthar forms were met with, the commonest amongst those that could be identified being *Nummulites granulosa,* d'A. and H., *Micropsis venustula,* D. and S., *Velates schmideliana,* Chemn. Above this limestone the section is hidden by talus up to a higher horizon from which the fossils obtained are nevertheless very similar, including *Nummulites granulosa,* d'A. and H., and *spira,* d'A. and H., *Micropsis venustula,* D. and S., *Velates schmideliana,* Chemn. At a slightly higher horizon some European forms were met with, *Cerithium van-den-Heckei,* Bell., and *Ovula bellardii,* Desh., of the upper eocene of Nice. The highest fossiliferous beds contain several species of *Cardita, Corbula, Natica, Turritella.* Dr. Noetling, who kindly examined them assigned them to the base of the Nari. Above these beds there is still a considerable thickness of unfossiliferous red shales containing a great deal of gypsum.

From Saindak to Robát.

From Saindak to Robát the strike of the ridges is generally constant being north-west. The syncline of eocene strata extends about eight miles north-west of Saindak. From there up to Kacha Kóh or even beyond, all the ranges consist entirely of strata of the volcanic flysch series. North-west of Kacha Kóh, at Piran Ziárat, there appear again green shales and calcareous sandstones probably of Ranikot age. The flysch strata consist of agglomerates and tuffs interbedded with greenish shales and sandstones that weather into brilliant colours, greatly resembling the rocks of the same age described in the Saindak section. Limestones also are frequent.

Indications of the great lateral pressure to which all these rocks have been subjected are present everywhere; they are nearly all more or less slaty often to a considerable degree. It is only in some

of the most massive and therefore unyielding rocks, such as some of the agglomerates or some of the more massive limestones, that this cleavage is less distinctly marked. In the region of Bogor, near the Kacha Kóh, the strike of the cleavage planes presents this particularity that it is more northerly than the strike of the bedding.

The mountain called Kacha Kóh is an anticline of dark coloured tuffs.

Along the north-eastern margin of the ranges where they overlook the Gaud-i-Zirreh depression there are several exposures of Siwaliks dipping inwards towards the ranges. In one place, north-west of Kirtaka, their junction with the older tuffs is exposed. It is a thrust-plane marked by a very much broken up limestone, the adjoining Siwalik clays being also very much crushed and broken. It is probable that the Siwaliks are continuous all along the north-east margin of the ranges, but that they are only occasionally exposed on account of their being concealed beneath the great talus that skirts the ranges. The great talus is furrowed by innumerable parallel ravines very much after the manner of the one described north of Nushki (page 9). They constitute such a serious obstacle to travelling that from Kirtaka the caravans cross the Persian boundary and proceed through Persian territory from Said Langar to Piran Ziárat along valleys in which the wild pistacio-tree grows somewhat abundantly.

At Piran Ziárat we find again an outcrop of those puzzling shales and calcareous sandstones already so often met with in the continuation of the Kójak range east of Nushki (page 40), at Mirui (page 61) and again in the Saindak section (page 80). But here their evident connection with the Ranikot strata of the Lar Kóh makes it quite clear that they too belong to that same age.

All along the north-east margin of the ranges from the Piran river up to Kóh-i-Malik-Siáh, the Siwalik strata are well exposed.

At Kirtaka, along the foot of the hills that overlook the Gaud-i-Zirreh depression, there are some terraces of fine silt which were probably formed at the time

Terraces of the Seistán lake.

when the water of the Seistán lake rose up to the level at which these deposits occur.

Robát.

The locality called Robát Kóh-i-Malik-Siáh is situated on the banks of a river-plain overlooked, on the north by the mountains called Robát Kóh and Malik-i-Siáh Kóh, while to the south rise the two masses of the Lar Kóh, the eastern one being usually called the Miri. All these mountains consist to a large extent of tertiary strata, mostly shales interbedded with calcareous sandstones and occasional limestone bands, and overlaid by a considerable thickness of nummulitic limestone. Instead of forming numerous parallel synclinal and anticlinal folds such as occur in the portions of the range so far described, these rocks show much less disturbance, the dips being low and uniform. The manner in which these regularly dipping masses are joined to the more closely folded ones is not seen clearly, much of the geology being concealed by the coarse alluvium of boulders that occupies the broad river valleys. It is probable that the great limestone, on account of its unyielding nature, has moved bodily, the structure being again somewhat that of a thrust-plane, as in the instances mentioned near Saindak. The shales immediately underlying the limestones have moved along with them and shared in the same uniformity of structure. Where they lack the covering of limestone as in the broad valley that separates the Robát Kóh mass from that of the Lar Kóh, they once more assume their more closely folded character.

The succession of strata is best seen on the north-eastern slopes of Robát Kóh (section Fig. 13 and Pl. VI). The lowermost strata are very badly exposed tuffs, overlaid by a considerable thickness 3,000 ft. or more of green shales and calcareous sandstones, with occasionally a more important limestone band. These shales are in turn overlaid by a considerable mass of thick-bedded limestone. Some of the lowermost shales contain *Orbitolites* and are probably upper cretaceous. Fossils were found both in the limestone *e* and in the lower beds of the upper limestone *g*, belonging in either case to the same species. The *foraminifera* are especially numerous and varied being represented by several species, some of which

are undescribed, of *Nummulites*, *Alveolina*, *Operculina*. There are some very large echinoids belonging to the genus *Conoclypeus* and numerous specimens of *Arachniopleurus semireticulatus*, D. & S., a characteristic form of the Ranikot of Sind.

The mountains of the Lar Kóh consist principally of a still greater thickness of the same limestone. It has sometimes a pseudo-conglomeratic appearance probably not unlike that described by several observers in the limestone of the Bolán pass[1] and of other parts of Balúchistán. Its apparent thickness is further increased by numerous intrusive sills which follow the stratification so regularly that they might be taken for interbedded lava-flows. Occasionally, however, they are seen to cut obliquely across the strata and in many cases their connection with vertical dykes is very clearly exhibited. Moreover their petrological characters are entirely different from those of a lava.

Intrusive rocks.

These intrusions which form such a conspicuous feature in the neighbourhood of Robát consist of hornblende-syenites and augite-diorites. They occur either as bosses of a more or less elliptical shape, or else as dykes and intrusive sills. The coarseness or otherwise of texture does not seem to depend always upon the shape and size of the intrusions: the diorites of Malik-i-Siáh Kóh and Robát Kóh are generally fine-grained notwithstanding the large dimensions of the bosses (Fig. 24), while in the Lar Kóh sills of moderate dimension are much coarser in texture. Some of the latter consist of an augite-diorite which is remarkable for also containing olivine. In some places, the large crystals of oligoclase exhibit a beautiful blue iridescence similar to that of some varieties of moonstone. Like the Rás Kóh syenite which it greatly resembles, this rock also contains silicate of copper or chrysocolla. The ore does not occur in distinct veins as at Drana Kóh (page 74), but like at the Rás Kóh it is irregularly scattered through the rock as one of its constituent minerals. In former times this ore seems to

Oligoclase moonstone.

[1] Mem. Geol. Surv. Ind., Vol. XVIII, p. 30; XX, p. 112.

have been smelted: there are large heaps of copper slag at Pain Robát in Afghán territory; but the ore may have been gathered from various other localities in the north-western continuation of the range in Persia. (See the chapter dealing with economic products.)

At Robát Kóh, in addition to the large bosses, there are also small dykes forming sometimes a perfect network of branching and anastomosing veins. When examined under the microscope, they are found to consist of the same minerals as the large bosses, but the texture is finer and the structure more porphyritic, as is also the case towards the edge of the greater intrusions and at their narrower extremities. At the edges of the great intrusions and in the smaller dykes, the igneous rock and the limestone with which it comes in contact have reacted upon one another, causing much alteration, especially amongst the ferromagnesian silicates. The adjoining limestone shows small veins and cracks full of epidote and the internal cavities of nummulites are filled with that mineral (spec. $\frac{14}{67}$). The occurrence of epidote as a product of contact metamorphism in limestones is uncommon, although instances have been recorded from other regions.[1]

Contact effect.

In addition to these dykes, the limestone at Robát Kóh is traversed by others, usually of very small dimensions, whose mineralogical constitution is quite different: these are highly basic or even ultrabasic basalts. One dyke only 18 inches wide contains small crystals of labradorite and augite in an almost perfectly isotropic groundmass. Another specimen from a larger dyke is a limburgite consisting of a very imperfectly crystalline base, with large porphyritic crystals of augite, and perfectly clear olivines, sometimes curiously intergrown. The remarkable freshness of the latter rock makes it appear as if it were newer than the dioritic intrusions; but I have not observed any instance of the one

Limburgite.

[1] J. Roth, Chemische Geologie, Vol. I (1879), p. 430; J. W. Judd, Propylites of the Western Isles of Scotland. Quart. Journ. Geol. Soc., Vol. LIII (1890); A. Lacroix, Mineralogie de la France, pp. 139, 152.

rock penetrated by the other. In this connection, reference may be made again to the very fresh lava, possibly of Siwalik age, that was mentioned in a previous chapter (page 30). It occurs at a short distance from these very recent looking dykes. The question is an interesting one and deserves further study: it is quite possible that they represent a period of volcanic activity older than that of the most recent volcanic outbursts, though quite distinct from the flysch eruptions of cretaceous and lower eocene times. To the same comparatively recent age might belong the deposits of ochres formed by solfataric action along fissures such as were mentioned at Saindak (page 79). These bright coloured ochres are again conspicuously developed in some parts of Robát Kóh, where they are impregnated with sulphate of copper, sulphate of alumina and sulphate of magnesia. Furthermore, some recent deposits of travertine occur upon the eastern slopes of Kóh-i-Malik-Siáh and west of Lar Kóh, indicating the former presence of thermal springs, though their situation in the neighbourhood of the formations just described might be a mere coincidence.

Recent gravel terraces.

Great masses of sub-recent gravels occur at various heights above the present bed of the broad valleys occupied by the Lar river and the Shamidar or Robát river. Like the terraces of silt at Kirtaka, they bear witness to the high level which the water formerly reached in the lake that occupied the Seistán depression. Plate XII shows these gravels in the Lar river capping highly tilted Siwalik strata. A similar feature may be observed in Plate VII.

From Robát to Ladis.

The return journey from Robát to Mirjawa was accomplished through the Persian province of Sarhad. The alluvial plain of Mirjawa (see *ante*, page 77), north-west of that locality, shares the fate of the "Dasht-i-Tahlab"; it becomes gradually narrower until the mountain ranges which it separates unite into one folded region. Thus the region visited exhibits nothing but numerous parallel ridges without

any broad depressions to separate them into distinct groups. Some plains do exist, for instance the dreary plain of Duzdap, but they are situated at a high level and do not mark off any differences of structure.

The sedimentary rocks met with are nearly all tertiary with the exception of some outcrops west and south of the Lar Kóh which may belong to the upper cretaceous part of the flysch. Everywhere the degree of disturbance is very great, the tertiary rocks being affected by slaty cleavage to a greater extent than in any of the regious hitherto described.

Immediately west and south of the Lar Kóh the strata are not only affected by cleavage, but are further altered to a considerable extent by igneous intrusions accompanied by solfataric action which has coloured them in an extraordinary manner. Owing to these circumstances the rocks are so much altered that it is difficult to identify them. They consist principally of limestones, shales and calcareous shales, sometimes sandstones associated with volcanic tuffs. In most cases, however, the volcanic beds are entirely wanting, and all the ridges consist of shales or rather slates with occasional limestone bands; these limestone bands contain nummulites, which can leave no doubt as to the tertiary age of the rocks. At Duzdap spring, some volcanic strata of the flysch period are exposed owing to the presence of an anticline, but south of that point all the sediments met with along the line of march were tertiary.

South-west of the Lar Kóh the strike of the strata is very unsteady: it is usually N. N. W. or N. W.; the cleavage planes generally striking north-south. But at Duzdap spring and further south the strike becomes N. W. or even W. N. W. There are many variations from place to place, but as my observations were taken along a single line it is not possible to tell how they are connected.

Intrusive rocks.

Between Palez (north of Kóh-i-Khwája-i-Misk) and Deri Giaban (called Deri Gumbaz on map) there extends a considerable outcrop of plutonic rocks comparable in size to the still larger intrusion of Rás Kóh. The outcrop is

about twenty miles long and its maximum width is about five miles. But many smaller dykes of similar composition occur to the north and south-west. The main mass of the intrusion consists of granite, the surrounding dykes of quartz-porphyries and quartz-felsites. The peaks called Kóh-i-Khwája-i-Misk, Kóh-i-Bibi-Mah, Kóh-i-Borghar, Kóh-i-Hanjirdán, all belong to the main granitic outcrop; in the plains and valleys that separate them from one another the granite has weathered into very typical "tors". South-east of Kóh-i-Khwája-i-Misk there are some dykes of diorite-porphyry.

The tertiary slates throughout the neighbouring districts exhibit a very extreme type of regional metamorphism. Cleavage is most perfectly developed, and they are altered into a very fine silky micaceous material which produces a dazzling reflection in the sunshine (see Pl. XIII). At their junction with the granite the effects of contact metamorphism are added to those of regional metamorphism, and the strata become so much indurated that they resist desintegration almost as well as the granite itself. In this way they rise to a great height along the slopes of the Hanari Range, a line of granitic peaks forming the south-eastern continuation of Kóh-i-Bibi-Mah. White mica, biotite, and garnet are amongst the most conspicuous of the minerals developed by this contact metamorphism. The altered rock is usually dark coloured, but where the slates have only been affected by regional metamorphism they often exhibit brilliant green and red hues in addition to their usual buff colour. Many of the limestone bands still contain recognizable nummulites, which shows that all these intensely metamorphosed rocks are tertiary.

Quartz veins of large dimensions occur frequently both in the granite and in the tertiary slates.

From Ladis to the Kóh-i-Tafdán.

South-east of Deri-Giaban the ranges of tertiary slates continue unaltered in their characteristics up to Ladis, a locality situated on the south-western border of the Mirjawa plain. The Ladis river derives a perennial supply of water from the snows of the Kóh-i-Tafdán, which permits a certain amount of cultivation in the

surrounding valley. As the river approaches the Mirjawa plain, terraces of recent gravel and of silt are largely developed. The Ladis river is a tributary of the Mirjawa river, which under the name of Tahlab river enters the Hamun-i-Mashkhel. The terraces seen here just as those north of Dalbandin (page 61) and elsewhere are no doubt connected with the former existence of a much higher water-level in the Hamun-i-Mashkhel depression.

When travelling from Ladis to visit the Kóh-i-Tafdán, I followed the course of the Ladis river and of one of its tributaries towards the village of Timi, which enabled me to examine the ancient strata exposed along its bank as far as the point where they become concealed beneath the recent volcanic deposits of the Kóh-i-Tafdán. The direction followed is roughly south-south west, which is practically at right angles to the strike of the ranges. At first the strata are the same tertiary slates and limestones as at Ladis. These are followed by volcanic rocks with the flysch facies, then again by a syncline of tertiary strata, and once more by the flysch which are the rocks exposed at the point where they become concealed beneath the escarpment of the recent ash-beds from the volcano (see frontispiece). An inlier of the same rocks rises amidst the ash-beds at Timi.

CHAPTER II.—RECENT VOLCANOES.

There exist, as pointed out by Mr. Blanford, two separate volcanic districts in Persia, one in North-Western Persia and one on the south-eastern frontier.[1] The western portion of the region examined by me contains the most eastern cones of the south-eastern district. Two large volcanoes were visited, the Kóh-i-Tafdán and the Koh-i-Sultán, both of which consist of compound cones of ash-beds and lava-flows. In the neighbourhood of the Kóh-i-Sultán there are a number of smaller lava-cones, mostly of andesitic nature like the larger volcanoes. Lastly, there are a great many deposits of travertine, even in regions distant from the actual volcanic foci.

Various travellers have asserted the existence of active or dormant volcanoes in Eastern Persia, even as early as the beginning of the century. Pottinger gives some very interesting information respecting the Basman volcano.[2] But up to the present day accurate information has been very scanty. The eruptive products from these volcanoes are both explosive and effusive, giving rise to ash-beds as well as lavas. They nearly all belong to one class of rocks, that of the andesites. They consist very largely of oligoclase felspar and do not contain any free quartz. They are nearly always very scoriaceous, so that their specific gravity is not readily ascertained. By means of special tests, General McMahon has determined it in a number of specimens.[3] The numbers found are somewhat low, which shows that the rocks are of a comparatively acid type approaching that of the trachyte group, from which they are removed nevertheless by the absence of orthoclase. Some slightly more basic types do also occur, but sparingly. A great many of these rocks contain a hornblende of an exceptional type which was described by General McMahon as a rhombic amphibole and by Mr. Holland as a soda-hornblende.

Andesitic eruptions.

[1] Eastern Persia, Vol. II, p. 468.
[2] Travels in Beloochistan and Sinde, p. 179.
[3] Quart. Journ. Geol. Soc., Vol. LIII (1897), p. 295.

The Kóh-i-Tafdán.[1]

The largest of the volcanoes visited is the Kóh-i-Tafdán in Persia. It still shows signs of activity. Owing to the Balúch's corrupt pronunciation of Persian the word has been variously spelt *Daftan*, *Daptan*, *Diptan*, and *Taptan*. It is also called Kóh-i-Chehiltán. In atlas maps it is often indicated as "Kóh-i-Taftán" or "Kóh-i-Naushada," which means "the mountain of sal-ammoniac." But this is a confusion arising from the fact that the latter name belongs to another volcanic cone not far distant, the Kóh-i-Basman. Upon enquiry I found that none of the inhabitants in the district of Ladis know of any other names but Kóh-i-Tafdán and Kóh-i-Chehiltán as applicable to the mountain which is about to be described, while Pottinger gives the name Kóh-i-Naushada to the Basman volcano.

Previous observers.

The earliest mention that I have found of the Kóh-i-Tafdán is in Háji Abdúl Nabi's account of a journey through Balúchistán.[2] It is mentioned also by W. T. Blanford,[3] Sir C. M. MacGregor,[4] General and Captain McMahon.[5] It was ascended in December, 1893, by Colonel Sykes and by Major Brazier-Creagh.[6]

Size of cone.

I only visited its northern slopes; but in that direction the distance from the highest summit of the peak up to the edge of the volcanic formation is over twelve miles. If the volcano extends to as great a distance in every direction, its diameter must be as much as twenty-five miles, exceeding in superficies the dimensions of Etna.

When travelling from Ladis to Timi along a tributary of the Ladis river the first recent volcanic formation met with is a buff-coloured rock terminating northward in a low scarp and overlying the ancient flysch strata (see frontispiece). This buff-coloured rock is formed of ash-beds dipping away from the centre of the great volcano at a very

[1] Wrongly spelt Kóh-i-Taftán on the maps; tafdán = smoking.
[2] Journ. As. Soc. of Bengal, Vol. XIII (1844), pp. 694-96.
[3] Eastern Persia, Vol. II, p. 481.
[4] Wanderings in Balochistán, p. 190.
[5] Quart. Journ. Geol. Soc., Vol. LIII (1897), p. 292.
[6] Geogr. Journ., Vol. X (1897), p. 586.

low angle. It consists of finely comminuted *débris* together with volcanic pebbles which vary in size from the smallest ash up to fragments of about one decimetre at most. In some exceptional instances, where ash-beds are exposed nearer the central cone, some much larger boulders were observed. These ash-beds are very similar to those of the Kóh-i-Sultán. They have been deeply cut into by streams forming gorges bordered by cliffs. These valleys are, however, very narrow; everywhere else the surface of the ash-beds presents a gently undulating surface, denudation having acted only locally.

Ash-beds.

In all the portions of the volcano which I have visited, these ash-beds are the oldest formation. The explosive eruptions that produced them were succeeded by the outpouring of great flows of lava. These flows appear to be of great thickness; at Timi they terminate in a northward direction by a rather steep escarpment, rising above the imperceptibly sloping surface of the ash-beds. From this point up to the base of the central peaks there rises a broad shallow cone entirely composed of lava, whose gentle slope is only locally interrupted by scarps of similar appearance to the terminal scarp at Timi, and indicating the end of a lava-flow. This gigantic slope must be composed of many successive lava-flows in superposition or in juxtaposition. This would probably be ascertained by examining some of the ravines which the rivers have cut through their mass. So far as mineralogical characters go there does not seem to be much to distinguish the lavas from one another, all the differences which I have observed being variations of texture such as may be frequently observed, even in different portions of a single lava-flow. The surface of these enormous fields of lava has become weathered into irregularly-sized boulders thickly carpeted with aromatic shrubs.

Lava-flows.

The double central cone itself consists entirely of lava which has solidified at high angles. The south-eastern peak appears newer than the north-western one; its shape is that of the latest flow of lava which has solidified half-way down its slopes, while the lavas

that build up the north-western cone have been irregularly cut into by denudation. It is from the south-east cone that vapour issues; it is given forth in considerable quantity, so that although there may not have been any outpouring of lava of late years, yet the volcano has not entirely ceased to be active. It is probably in the "solfataric" stage. It is unusual for an active volcano to rise at such a distance from the seashore: Kóh-i-Tafdán is about 240 miles distant from the Arabian Sea. But as Asia is the most massive of all the continents it is naturally there that such exceptions may be expected.[1] Geologists have pointed out that volcanoes are formed where great and sudden differences of level occur in the surface of the earth's crust, and nowhere are these differences so much marked as along some of the sea-coasts, which would explain the position of so many volcanoes near the sea. It is quite possible that considerable differences of level are concealed by the enormous thickness of recent deposits in the deserts of Central Asia.

I did not ascend up to the summit of the mountain, but the vapour appears to issue from the southern side of the peak. It issues at regular intervals of time, in very large volumes visible from a distance of several miles.

Where sections of the lavas are exposed in ravines they exhibit normal characters; flow-structure is very distinctly seen and the scoriaceous nature of both the upper and lower portions of the flow is also distinctly shown. The lower scoriaceous portion is often quite cavernous, some of these natural caverns being spacious enough to be used as dwellings. Many other dwellings have been artificially excavated in the soft ash-beds. As it often happens in volcanic areas this cavernous lower portion of the lava affords an easy passage to water, which is frequently seen gushing out from the junction of the lava and agglomerate. The spring known as the "Fountain of Moses" in the valley above Timi is of that nature.

[1] Some of the American volcanoes, though not so far removed from the ocean as the Kóh-i-Tafdán, are by no means in the neighbourhood of the seashore; for instance, Cotopaxi is 160 miles distant from the Pacific Ocean, while Popocatepetl is situated at 160 miles from the Pacific Ocean, and 140 miles from the Gulf of Mexico.

The Kóh-i-Sultán.

The Kóh-i-Sultán derives its name from that of the most celebrated and most respected of all the "Pirs" or saints who form such a curious feature in the religion of the tribes that inhabit Balúchistán. With reference to this "Pir Sultán" or "Pir Kisri," Ferrier, with great justice, says of the Balúchis, that "although acknowledging that Mahomet is a prophet there is another they consider of much greater importance than he, and as second only to God, with whom they sometimes confound him."[1]

Previous observers.

Situated as it is in a very inaccessible position in the heart of the desert, this mountain has attracted very little notice from travellers. Its name was mentioned from secondhand, or rather thirdhand, information by Bellew in 1862, and it is evident that his informant was not quite clear about the separate existence of the Kóh-i-Sultán which he calls Pir Kisri, and the Kóh-i-Tafdán which is called Cháh-i-Dúdi, "the smoking well."[2] Some distant views of the mountain are given by MacGregor in his "Wanderings through Balochistan," and it has been described by Captain McMahon.[3]

Physical and geological features.

The Kóh-i-Sultán is an oval-shaped mountain, whose longer axis, striking west-north-west, is about 17 miles, the transverse width being about 10 miles. It is an extinct volcano consisting of rocks very similar to those of the Kóh-i-Tafdán; but instead of forming one cone the centre of eruption seems to have shifted several times, so that the mountain is really an aggregate of three distinct cones, now greatly denuded, whose centres are disposed along one straight line. As in the case of the Kóh-i-Tafdán the earlier eruptions were mostly explosive, the later ones effusive, but the more or less continuous covering of lava-flows, which, no doubt, at one time capped the great accumulations of tuffs,

[1] Caravan Journeys, p. 432.

[2] Journal of a Political Mission to Afghanistan in 1857, by H. W. Bellew (1862), pp. 278-279.

[3] Geogr. Journ., Vol. IX (1897); Quart. Journ. Geol. Soc., Vol. LIII (1897).

as it still does in the Kóh-i-Tafdán, has been scoured to such an extent by watercourses that it is reduced to isolated masses forming gently sloping plateaux round the periphery of the mountain.

The original summits of the three cones have been entirely denuded away. The western cone has been denuded to such an extent that it now forms a great circular plain four and a half miles in diameter, surrounded by a beautiful amphitheatre of cliffs. It is an instance of the kind of feature termed by Lyell a "crater of denudation."[1] All the drainage of this amphitheatre is gathered into one channel, the Gam-i-Cháh river. The cliffs that surround this amphitheatre consist almost entirely of accumulated ash-beds (Pl. XIV). They do not everywhere rise to the same height in one unbroken line, but have been variously shaped by the agencies of denudation; some portions which have been less denuded stand out as isolated masses or as outstanding pillars like the Neza-i-Sultán. Photographs of the latter object, published in the *Geographical Journal* and the *Quarterly Journal of the Geological Society* do not show its connection with the surrounding hills and led to some discussion at the time when Captain McMahon read descriptions of the mountain. The Neza is only an unusually lofty mass of ash-beds isolated by denudation. The beds composing it dip south-east at a well-marked angle.

The second cone seems to have had its centre in the neighbourhood of the great masses of lava called Kóh-i-Abú (Pl. XV) and Mián Kóh. The circular outline of this second cone is less easy to follow on the map (see map 3) than that of the western one, probably on account of its more heterogeneous composition; for while the western cone consists almost entirely of ash-beds, this second cone contains a large proportion of lavas, principally in its central portion. Moreover, eruptions may have proceeded simultaneously or alternately from this cone and from the western one, which would have further contributed to increase its irregularity.

The eastern cone has been denuded into scarped masses of

[1] Quart. Journ. Geol. Soc., Vol. VI (1850), p. 207.

great magnitude also grouped in a circular manner. It consists principally of accumulations of fragmentary materials and contains the highest summit of the mountain, the "Miri," which rises to an altitude of 7,656 feet.

A thorough examination of the mountain would result in unravelling all the details of its history. By examining the manner in which beds of various nature overlie one another, by ascertaining the mineral characters of the various lavas, it would be an easy task to assign to them in every case their relative age and their point of origin. I remained only one week in the mountain; it is not possible for me to tell with certainty the order in which the three cones made their appearance. The eastern cone is probably the newest, judging from the fact that it still contains the highest summits, notwithstanding the extremely friable nature of its ash-beds, which have been greatly decomposed by solfataric action. On the other hand, the broad denuded circular plain and ruined cliffs of the western cone point to a greater antiquity. The remnants of lava-flows that cap the agglomerates and tuffs, forming conspicuous gently inclined plateaux round the periphery of the mountain seem to be the *débris* of streams of lava that proceeded from the second or central cone. Those that overlie ash-beds of the western cone were poured over an extremely irregular surface, showing that the western cone had been denuded to a considerable extent at the time of the eruption of the lavas.

Thus the three cones appear to have succeeded one another in the direction from west to east; but the eruptions may have been partly simultaneous judging from the manner in which beds dipping in opposite directions overlap one another.

Lava-flows.

The lavas above mentioned, which denudation has separated into long strips, probably formed at one time a continuous outcrop analogous to the one of the Koh-i-Tafdán. The flows are of considerable thickness, of a grey colour, with very imperfect columnar structure or quite irregular jointing, and are petrologically very similar to those of Kóh-i-Tafdán,

They belong to a late period of the history of the volcano as is shown by their stratigraphical position and by the great amount of denudation undergone by the underlying ash-beds previously to their appearance. On the other hand, there exist also some older lava-flows interbedded with the ash-beds and agglomerates. There are also some lavas which seem newer still than those of the great inclined plateaus, and are probably the latest products of activity. They occur at the junction of the second cone with the eastern one and are shown on the map with a purple colour. They are more basic than most of the other rocks. They show a distinctly columnar structure and occur at very variable altitudes, frequently occupying the bottom of valleys, so that when they were ejected the topography was already not unlike what it is to-day.

Ash-beds, tuffs, etc.

The fragmentary beds which form the most considerable portion of the volcanic deposits are of various degrees of coarseness, from the finest ash up to masses consisting of boulders as much as one foot in diameter. All these fragments are irregular and angular. There are also found occasionally some real "bombs" which were ejected in a molten or pasty condition and which have a chilled outer crust (specimen $\frac{13}{857}$). The desintegration of these ash-beds has produced a gigantic talus forming a deeply ravined slope all round the mountain. The materials of all sizes have been reconsolidated into beds which so resemble the ash-beds from which they were originally derived that it is often difficult to tell whether it is the result of former eruptions or of later desintegration, a distinction rendered still more difficult owing to the fact that denudation was proceeding simultaneously with the later eruptions.

The fragments that constitute the agglomerates and ash-beds consist of andesitic lavas of the same class as those that form the lava-flows. When unaltered they exhibit the same grey colour, but usually they have undergone a certain amount of chemical alteration, probably of a solfataric nature, which has coloured them in exquisite shades of salmon pink, buff, green, mauve, and many other tints. These

wonderful colours, combined with the exquisite shapes of the cliffs, give to the scenery a degree of beauty which it would otherwise lack on account of the almost complete absence of vegetation.

The degree of alteration which has produced these colours is of a moderate degree; but in other places the mineral vapours have altered the rocks far more completely. The volcano was a solfatara in one of its last stages, which is probably also the stage now reached by the Kóh-i-Tafdán. It is in the eastern portion, principally all round the "Miri," that the effects have been most pronounced, but other patches of similarly affected rocks have been observed further west, the most important ones being shown on the map, and a portion of the volcano Damodim, west of Kóh-i-Sultán, also exhibits the same phenomena. The scenery all round the Miri Hill is of the most extraordinary character, slopes thousands of feet in height being entirely coloured in the most brilliant tints of red and yellow. All the rocks, whether agglomerates or lavas, have been transformed into soft clays of bright colours. Where the transformation has not proceeded so far, the shapes of the minerals can still be discerned, but generally every original character has been obliterated, save occasionally the stratification. Owing to their friability, these altered rocks have not weathered into the same vertical cliffs as elsewhere, but they are cut up into innumerable ravines with countless branching furrows and ramifications, in the manner which characterizes the denudation of a homogeneous argillaceous rock.

Solfataric action.

These clays are all impregnated with sulphate of alumina, which is extracted and used as a mordant, under the name of "Kóh Mak." In this country, where it does not rain for years at a time, it gradually effloresces in the shape of white tufts, which are collected under the name of "Phúl Mak." I did not see the latter substance, as an exceptional shower of rain had destroyed it just before my visit. Some pale yellow clays contain soluble salts of iron in addition to those of alumina. The iron salts combine with certain vegetable substances and with the sulphate of alumina to form

dyes of various colours as is described by Major Brazier-Creagh,[1] who collected a similar material near the Kóh-i-Tafdán. The bright-red clay called "Gilik" is used for marking sheep. These soft clays with their associated minerals have been formed by the action of mineral vapours. They are full of large plates of gypsum and occasionally contain sulphur, which is also extracted. The ore is placed in large cauldrons built over a fireplace in which brambles are burnt; a man stirs the sulphur, while it melts; the lighter impurities are skimmed off the top with a flat ladle, the heavier ones sink to the bottom, and the sulphur is finally decanted into basin-shaped moulds. This industry has been carried on for ages by a family living in the Afghán Province of Garm Sel. The Kóh-i-Sultán and all the minerals which it contains are looked upon as the special property of the mythical Pír Sultán who is supposed to reside there. None of this land can become private property. One-tenth of the value of the sulphur and sulphate of alumina is given away in charities as a right of work (the same rule is followed by the people who collect asafœtida, the plant being common in some parts of the mountain).

Extraction of Sulphur.

In addition to chlorinizing and sulphurizing actions, silicification has also taken place in some localities. Superheated vapours charged with silica have found their way through vertical cracks and little by little the substance of the rock has been replaced by silica, causing the altered portion to resist weathering better than the unaltered rock, so that it stands out resembling a dyke. These silicified rocks occur often at quite a distance from the main regions of solfataric action (specimens $\frac{13}{897}$, $\frac{13}{898}$). Sometimes the silicified rock is surrounded on either side by a narrow zone transformed into clay and gypsum. Sometimes the vapours have followed a plane of stratification making one stratum quite hard. The substance of the rock has been replaced so gradually that the shapes of the fragments in an

Silicification.

[1] Rec. Geol. Surv. Ind., Vol. XXX, p. 253.

agglomerate or the outlines of crystals are often perfectly clear, although nothing remains of the original substance, the case being, no doubt, similar to that of the structures so well preserved in silicified wood. In a few instances the silica has been coloured green by slightly cupriferous emanations.

The great cliffs of agglomerates of the Kóh-i-Sultán produce the most wonderful echoes, a word being repeated distinctly in some places as many as five times. To these echoes I would attribute a curious sound which is supposed to be that of a war-drum or "Naqara" played by the Pír Sultán during certain nights. This performance is supposed to take place on the summit of Shandi-Kóh, one of the peaks of the western circle of cliffs. I heard this sound on one occasion when I was encamped at Washáb, a short distance east of Shandi-Kóh. It is a clear, high-pitched, slightly vibrating sound, not unlike the distant roll of a somewhat metallic drum, now becoming fainter, now swelling till it becomes astonishingly loud, and it is heard for hours at a time in the dead of night. The night when I heard this sound was a very calm night. It may be that when there is very little wind in the valleys, the noise of the breeze on the hill-tops is exaggerated by the echo. It would be interesting to find out whether it is only with the wind blowing in certain directions that the sound is heard.[1]

The "magic drum."

All over the alluvial plain north of the Kóh-i-Sultán are scattered numerous blocks of pumice. I have not observed from which point they were derived, it is probably from the unexamined portion at the eastern extremity of the mountain. At Washáb there are some tuffs entirely made up of small fragments of pumice (specimen $\frac{13}{868}$).

[1] This myth of the Pír Sultán, like many other myths of this region of Balúchistán, is no doubt of pre-Mahometan origin. Mr. Tate, who by his thorough knowledge of oriental languages, has been able to collect a great deal of interesting folk-lore, informed me that it is not allowed to kill snakes in the Kóh-i-Sultán and the neighbouring districts as these animals are supposed to be under the protection of the Pír Sultán, apparently a remnant of an ancient snake worship. In addition to playing the drum, the Pír Sultán is occasionally heard and seen riding about the mountains at night. It is very curious that there exist absolutely similar legends in Central India in connection with a spirit called Pir Maharaj, who is worshipped both by Hindus and Mahometans.

Damodim.

West of the Kóh-i-Sultán rises the volcano Damodim. Its shape is that of a truncated cone about four miles and a half in width. All the outer portion of this cone is a talus formed by denudation. Considering the amount of denudation which has taken place, the circular shallow crater or rather plateau at the summit is difficult to explain. On its western and northern side this plain is limited by steep-sided peaks; on the southern and eastern sides the rim rises in very low hills or even the edge of the plateau is quite shallow. This flat plain is more than one mile in diameter. It cannot represent a crater of the ordinary type of a cinder cone, for the rim is very heterogeneous in composition: the three peaks to the west and the one to the north consist of massive rock; whether they represent part of a volcanic neck or fragments of a lava-flow is difficult to decide, they appear so structureless. The rest of the rim of the crater consists of agglomerates resembling those of the Kóh-i-Sultán. It is possible that the last eruption of the volcano may have been of a violent explosive nature producing a deep cavity; owing to the dryness of the climate, this did not give rise to the formation of a lake, and the rim under the influence of desintegration and denudation gradually collapsed both inwards and outwards until the central cavity became the scarcely concave plain of to-day.

After an unusually heavy shower of rain a shallow sheet of water remains for some time in the centre of the plain which is covered with fine alluvial silt derived from the taller peaks of the rim. This supposition of a very violent explosive eruption would account for the enormous proportions of the surrounding talus and the huge size of the boulders composing it.

On the eastern slopes of Damodim the rocks are altered by solfataric action in the same manner as those of the Kóh-i-Sultán.

Massive Cones of Lava.

The volcanoes so far described are both explosive and effusive. In fact, the fragmentary deposits due to explosive eruption seem to

be somewhat in excess of true lavas. There remain to be noticed some smaller cones of very recent date consisting entirely of lava, all of which occur in the neighbourhood of Kóh-i-Sultán; the date of their eruption is far more recent than the period of activity of the Kóh-i-Sultán and the Damodim. When undenuded they have a roughly hemispherical shape which is not a result of subsequent weathering, for their desintegration has only given rise to a limited talus beyond which no fragments occur. The lava was erupted in a viscous or pasty condition and solidified at high angles without flowing to any distance, giving rise to a type of hill which is well known by the Puy de Dôme in Auvergne and the other trachytic bosses in its neighbourhood. Kóh-i-Dalil is comparable in size to the Puy de Dôme, perhaps even larger. Batil Kóh (Pl. XVI) is of smaller dimensions; it rises on the southern talus of the Kóh-i-Sultán and its stratigraphical relations to that talus constitute a proof of its very recent date. This southern talus is furrowed by innumerable ravines, and the Batil Kóh rises upon the ridge between two of these valleys; it has not in the slightest way deflected the watercourses nor affected the general shape of the ridge as may be seen on the map and in the figure. Thus at the time of the eruption the talus presented practically the same topography as it does now, and the denudation of the Kóh-i-Sultán had proceeded about as far as at the present day. Fragments of the boulders of lava forming the talus were observed caught up in the Batil Kóh lava. The lava of Batil Kóh is remarkable for the fact that it contains olivine, in perfectly clear transparent grains of a very pale straw-yellow.

Batil Kóh.

The Kóh-i-Dalil, about fifteen miles east of Damodim, is of similar structure to Batil Kóh. It is of considerable size forming a conspicuous object visible from a great distance. The lava is a trachytic looking andesite with a rudely columnar structure. Where slightly altered the rock has a brick-red colour; it is grey when fresh. It is very porous, the upper surface of the lava being quite scoriaceous. Petrologically it is

Kóh-i-Dalil.

quite similar to many lavas of the Kóh-i-Sultán and the Kóh-i-Tafdán; the peculiar hornblende which characterises so many of these lavas is very abundant in the Dalil lava.

Mit Kóh, etc.

The volcano Mit Kóh, N. by E. of Amír-Cháh and separated from that locality by a broad belt of sand dunes, is very conspicuous, owing to its red colour and its isolated position. It has suffered from denudation more than Batil Kóh and Kóh-i-Dalil, so that it has lost its regular hemispherical shape. It is surrounded by a broad talus very much invaded by wind-blown sands.

About half way between Mit Kóh and Kóh-i-Dalil, almost in an exact straight line with them, is a very small volcano not much more than one hundred feet high, which occurs on the south side of the track from Amír-Cháh to Zeh. It consists of a very fine-grained black andesite which becomes red on weathering, together with a few scoriæ. It has a crateriform shape, the crater being indented by the lava which has not flowed to any distance. Like Batil Kóh, this little volcano has a very recent appearance; the lava contains a large number of small crystals of olivine.

Other Volcanoes.

The volcanoes above described are but the eastern portion of a large volcanic district, which occupies a great part of eastern Persia, as can be inferred from the narratives of previous travellers. Thus

Kóh-i-Basman.

the volcano of Kóh-i-Basman, also called Kóh-i-Naushada [1] and Meh-Kóh [2] appears to be comparable in size to the gigantic Kóh-i-Tafdán. Although no mention is made of any column of vapour similar to the one which forms such a conspicuous feature in the Tafdán mountain, yet all accounts seem to show that the Basman volcano also exhibits some signs of activity. Pottinger gives a most interesting account of a thermal spring which occurs at the village of Basman, about fifteen miles from the mountain.[3] The specimens of lava which Major

[1] Pottinger, Travels in Beloochistan and Sinde, p. 180.
[2] W. T. Blanford, Eastern Persia, Vol. II, p. 481.
[3] Travels, p. 179.

Brazier-Creagh collected on the cone are remarkably similar to those of the Tafdán and Sultán volcanoes, and like them contain the same exceptional hornblende.

Mr. Blanford mentions the occurrence near the Narmashir desert of a number of perfectly fresh-looking volcanic cones. From his description, it appears that there are two different series, an older one of well consolidated rocks which have undergone a moderate degree of disturbance, and a newer one overlying the former, and which are described as "chiefly ashes and vesicular blocks of comparatively recent origin, with a few outbursts of basalt, which are doubtless lava-flows.[1]" The specimens from this newer series, which are preserved in the Survey collection, are andesites, often highly scoriaceous, which appear perfectly fresh.

Other cones exist, no doubt, in southern Afghánistán: the specimens from which Mr. Holland described the peculiar hornblende so common in these rocks, were obtained by Dr. Maynard near Malik Dókhand.

To the west of the Kóh-i-Tafdán, and connected with it by high ground, is a group of mountains that rise to a considerable height, several peaks exceeding an altitude of 10,000 feet. At the distance from which I saw them, they seem to consist of stratified rocks which exhibit uniform and moderate dips, thus differing in appearance from the usually contorted structure of the older formations. They form stupendous cliffs of shapes not unlike those which have been carved by denudation in the Kóh-i-Sultán. The specimens of coloured clay or "Mak" collected by Major Brazier-Creagh were labelled, "Chehltan range"[2] and were probably derived from these hills, which would represent an older ruined volcano that preceded the modern Kóh-i-Tafdán.

Further, as has been several times mentioned in the previous chapters, it is possible that some distinctly older eruptions occurred during the pliocene period. This is perhaps the age of the older

[1] Eastern Persia, Vol. II, p. 482.

[2] Colonel Sykes also speaks of these mountains as the Taftan range. Geog. Journ., Vol. X (1897), p. 573.

series observed by Mr. Blanford in the Narmashir district. The volcanic activity may have traversed the same phases as in other regions, in Auvergne for instance, where the recent and sub-recent eruptions were preceded by pliocene and even miocene outbursts.

Mud volcanoes.

Lastly, it is well known that mud volcanoes have been observed in many parts of Balúchistán and Eastern Persia.[1] That they are phenomena connected in some way with real volcanic activity is admitted by many geologists, and, in the present instance, they would also therefore belong to the Eastern Persian volcanic district.

Terraces of Travertine.

Deposits of carbonate of lime, the products of former thermal springs, connected no doubt with volcanic activity, have been mentioned in a number of localities. The most considerable deposits are north of Jhuli (see *ante*, page 70) and at Tozgi (page 73). Similar deposits were noticed by previous observers in the neighbourhood of Kóh-i-Malik Dókhand in Afghánistán.

Deposits near Jhuli.

The travertine occurs in well stratified layers, but without forming a distinct succession of terraces disposed in successive steps, a feature now obliterated by denudation, for the hot springs that gave rise to the deposits have ceased to flow, and denudation had commenced acting before the deposition had entirely ceased. For instance, north of Jhuli, where the deposits cover a very large area and rise to a considerable height upon the hill-slopes, ravines have been eroded through the accumulations of travertine; but on the floor of these ravines, the

[1] Descriptions of the mud volcanoes of Balúchistán are given in—Transactions of the Geographical Society of Bombay, Vol. III (1839-40), p. 77: Pilgrimage to Hinglaj, by Captain S. V. W. Hart. Journ. Bom. As. Soc., Vol. III (1850), p. 8: Memoranda on mud craters in the district of Luss, by Captain A. C. Robertson Rec. Geol. Surv. Ind., Vol. V: Note on the Geological Formations seen along the coasts of Bilúchistán and Persia from Karachi to the head of the Persian Gulf, and on some of the Gulf Islands, by W. T. Blanford, p. 43. Quart. Journ. Geol. Soc., Vol. XXX (1874), p. 50: On the Mud Craters and Geological Structure of the Makran Coast, by Lieutenant A. W. Stiffe. Manual of the Geology of India, 2nd edition, p. 22. Geogr. Journ., Vol. IX (1897): The Southern Borderlands of Afghanistan, by Captain A. H. McMahon, p. 398.

weakened springs still continued depositing calcareous tufa in which blocks detached from the escarpments of the older formation became imbedded. At the present day there still issues a small spring which forms incrustations of rather pure common salt which is collected by the inhabitants of neighbouring districts.

A pale-coloured variety of this travertine acquires on weathering a smooth translucent surface, giving it the appearance of pale yellow wax, which is very pleasing to the eye. The weathered pieces are collected, and without being carved in any manner, they are largely used for the decoration of tombs. North of Jhuli this variety is obtained principally from the newer deposits. The fractured surface has a disappointing appearance: beneath the wax-coloured weathered surface the rock is nearly white and so coarsely crystalline that it is too brittle for any decorative purpose. The older deposits consist of a rock which, on weathering, assumes an unattractive brown colour, but which on fracture is found to be a very beautiful material. The carbonate of lime is of a delicate green colour, veined and banded with portions stained with iron, showing that the springs were also ferruginous in their earlier stages. The material is sufficiently tough to be obtained in fairly large pieces, and would form a very ornamental "onyx marble."

Deposits at Tozgi.

At Tozgi the rock is pure white and coarsely crystalline.

Mr. Holland has drawn attention to the fact previously noticed by Dr. G. E. T. Aitchison that this rock consists of alternating layers of calcite and aragonite.[1] Some specimens collected at Kóh-i-Malik-Siáh (page 88) consist entirely of fibrous aragonite.

Mr. Blanford has mentioned the occurrence of similar rocks in Persia.[2]

Parallel between the Western Malay and the Eastern Iranian Region.

In India there is a complete absence of any undoubted instance of a recent volcanic eruption, both in the peninsular and in the

[1] Rec. Geol. Surv. Ind., Vol XXX, p. 129.
[2] Eastern Persia, Vol II, p. 485.

extra-peninsular region. But both to the west and east, volcanoes appear in the two regions of curved ranges that join the great Himalayan arc both at its eastern and western extremities. Among the features common to the parts of those two regions that border upon India, are the numerous parallel ranges made up largely of marine tertiary strata, while in either case, the upper tertiary is represented by rocks similar in age and appearance to the Siwaliks of India. Mud volcanoes have long been known in either region, and the existence of real volcanoes of recent and sub-recent date must be added as a further connecting link. Kóh-i-Sultán, Koh-i-Tafdán, Basman Kóh, and the other volcanic centres of Eastern Persia form the counterpart of Barren Island, Narcondam, Puppa and other Burmese volcanoes. Nor is it only their geological age that is similar, but the lavas of which they are built are identical. The Burmese volcanoes also consist of andesites whose mineralogical constitution is quite similar to the Eastern Persian ones: just as in Eastern Persia, the presence of olivine is frequent, and the same varieties of pyroxene and amphibole are met with; a mineral very similar to the peculiar red hornblende of Balúchistán and Persia being very conspicuous in many of the lavas from Narcondam, where it was noticed by Mr. Mallet,[1] and in the lavas of Púppa.

[1] Mem. Geol. Surv. Ind., Vol. XXI, p. 282.

PART III.

PETROLOGY AND ECONOMIC GEOLOGY.

SECTION 1.—PETROLOGY.

The journey which I performed through Balúchistán, although not always favourable to geological observations on account of the great distances travelled through, afforded nevertheless from this very reason, an opportunity for collecting a most varied and extensive collection of rocks.

Two descriptions have been published of the specimens collected in 1896, during the Afghán-Balúch boundary commission, one by Mr. Holland, and one by General McMahon (see *ante*, page 6). Nevertheless the excellence of the material now at our disposal represented, as it is, by a collection of several hundred specimens, will still allow many important details to be added to these interesting studies. Although a great deal of preparatory work has been done, the study of such a vast amount of material has not advanced far enough to justify the publication of any results. It is, therefore, necessary to postpone, until some future occasion, the review of this important subject. The following is a short résumé of a few points that have been noticed :—

Classification.

On page 40, a classification was given, dividing some of the igneous rocks into three groups according to their geological age.

1.—Volcanic rocks of the "flysch" period, that is upper cretaceous and lower eocene.

2.—Intrusions, principally acid and intermediate, probably upper eocene.

3.—Basic intrusions cutting through those of group 2.

To these must be added a fourth group, that of the recent volcanic products which, if some of my observations be correct, would require a further sub-division into

4*a*.—Volcanic outbursts of Siwalik age, probably pliocene.

4*b*.—Recent and sub-recent eruptions.

It has also been noticed that the existence of these four independent series constitutes a source of great confusion wherever the age of the rock is not unmistakably established by the most distinct field evidence. For instance, three at least of these series, the groups 1, 2 and 4, consist of rocks which vary considerably in chemical composition, and in the present state of our knowledge of the geology of this region, it is often impossible to tell to which group certain intrusive rocks may belong. The volcanic formations of 4*b* have not been sufficiently denuded to exhibit any of their intrusive portions, but a basic intrusion might belong to any of the other subdivisions, while a more acid rock might belong indiscriminately to 1, 2, or perhaps 4*a*. Even in the case of a lava, as in the instance seen at Robát (pages 30 and 88), it becomes difficult to tell whether it belongs to an exceptionally unaltered outcrop of group 1, or an exceptionally disturbed outcrop of 4*a*.

In many cases, however, there can be no doubt as to the correct attribution of the rocks; and, although their petrological characters have been described in the works above mentioned, yet it is interesting to be able to group them according to their relative ages.

The rocks which are classed together as group 1, that is the volcanic rocks of upper cretaceous and lower eocene age, are mostly ash-beds and tuffs which often consist of intermingled fragments of widely different petrological characters. Almost every variety of lava is represented in these fragments, from a quartz-andesite to a highly basic basalt. A few lava-flows have also been observed, whose structure is usually somewhat brecciated, as is very commonly seen in rocks of this nature when they have been poured out under water.

The great intrusions and smaller dykes and bosses of group 2, which have been several times noticed in the descriptive portion of this Memoir, also vary in composition. Granites, syenites and diorites, both with and without quartz, have been met with. They often possess a truly granitic structure, or else, as at the edges of the

large masses, and in smaller dykes, they exhibit porphyritic characters. Some of the quartzless rocks are somewhat basic, though they never become typical gabbros and dolerites, at least not in any rocks which can be without any doubt attributed to this group.

Amongst the rocks with reference to which some doubt arises as to their proper attribution to group 1 or group 2, are some very interesting diorites and diorite porphyries that contain a large proportion of micrographic quartz. Some of them have been intruded amongst gabbros, and it would be interesting to study more closely the field-relations of the two rocks as the association of granophyre and basic rocks has already been noticed in other localities.

The rocks which have been referred to group 4*a* and which perhaps represent a period of volcanic activity of Siwalik age, are both intrusive and effusive. They are either intermediate or basic and are remarkable for the extreme freshness of their minerals. Some of them belong to somewhat exceptional types, for instance, a diorite porphyry apparently containing a felspathoid, in the desert near Kóh-i-Dalil, and a very beautiful limburgite which occurs as a dyke at Robát.

Lastly, the recent volcanic products that constitute group 4*b* are remarkably uniform in character as has been noticed in the chapter dealing with that formation. A great many contain a hornblende that exhibits some exceptional features.

The study of this vast collection is not yet sufficiently advanced to allow of any generalisations being formulated. The distribution of the minerals presents some noticeable peculiarities. In all the groups above mentioned, augite is a very plentiful mineral either to the complete exclusion of hornblende, or frequently associated with it. Sometimes this may be due to the transformation of augite into uralite, while the reverse change of hornblende into pyroxene is also seen in a great many rocks of group 4*b*. But in most cases, in which the pyroxene and amphibole are associated, they both occur as primary constituents of the rock.

Whilst augite is so common the mineral orthoclase on the other hand is very seldom met with. Where it is plentiful, as in some rocks of Rás Kóh, it is associated with augite, forming an augite-syenite. The diorites and granophyric diorites usually contain nothing but plagioclase felspar however great may be the proportion of quartz. Olivine is very plentiful even in rocks that are not basic, as was already noticed by General McMahon.[1] Sphene and apatite are often very abundant.

It is to be hoped that an opportunity may arise for completing the study of such an interesting collection. Many questions that require further field investigation cannot be elucidated for some-time to come on account of the inaccessible situation of some of the most typical outcrops. But enough material has been gathered to repay a thorough study of the collection.

SECTION 2.—ECONOMIC GEOLOGY.

Ores of copper, lead, and iron, and some other minerals of commercial value, such as sulphur, sulphate of lime and sulphate of alumina, have been met with in several localities. Some of them occur in small pockets as an original constituent of some of the igneous rocks mentioned in previous chapters. All the others are results of solfataric action, either in the recent volcanoes, or in connection with some basaltic intrusions that belong to an earlier period. None of the deposits observed are of great richness, and the physical drawbacks of the region, the absence of fuel and the difficulty of obtaining labour make it improbable that any satisfactory returns could be obtained under existing conditions.

Some of the varieties of travertine formerly deposited by hot springs connected with volcanic activity might be used as an ornamental stone.

Silicate of copper occurring as a constituent mineral of some igneous rocks.

Silicate of copper, or "chrysocolla" occurs disseminated through syenite in the Rás Kóh, south of Charsar in the State of Kharan, and through diorite, in the Lar Kóh in Persia, near Malik-i-Siáh-Kóh.

[1] Quart. Journ. Geol. Soc., Vol. III (1897), p. 298.

These syenites and diorites are intrusions of tertiary age; their mineral composition is somewhat exceptional. Notwithstanding their acid character and low specific gravity, they contain an abundance of augite and even olivine. The proportion of titanium and phosphorus must be unusually high judging from the number and size of the cystals of sphene and apatite. Near the junction with the sedimentary rocks, the syenite frequently contains silicate of copper, not in veins, but disseminated amongst the other minerals in grains of varying size. My observations were not sufficient to decide whether any of these masses would be large enough or especially continuous enough to allow of systematic working; the mode of occurrence in itself renders this improbable. Some men living at Charsar, where there is a little cultivation along a "káréz," remember having seen the metal extracted some thirty years ago, by a certain Dad Muhamad. This man merely collected out of the talus the pebbles containing copper ore, which are conspicuous on account of the green colour which they assume on weathering. These he pounded in a mortar and extracted the metal in a primitive manner, the smelting of chrysocolla being very easy.

At Robát, near Lar Kóh, there are some important remains of copper smelting works, in the shape of heaps of slag. The blocks of slag are so numerous that a small fort now ruined was entirely built of them. The only ores which I saw in the neighbourhood are silicate of copper disseminated through the syenites and diorites of Lar Kóh, and some veins containing carbonates of copper at Robát Kóh and Malik-i-Siáh Kóh. None of these deposits seem of sufficient importance to have yielded a large quantity of metal, and I did not see any remains of underground workings. It is possible that the ores smelted at Robát were obtained from some other spot which I have not visited, situated in the north-western continuation of the ranges in Persia. Khanikoff mentions the existence of large abandoned mines of lead and copper which are so situated.[1]

[1] Mémoire sur la Partie Méridionale de l'Asie Centrale, p. 169.

Ores occurring in veins.

All the other ores observed seem to have been the result of solfataric action. All the rocks older than the Siwaliks, whether they be intrusive or sedimentary, are frequently traversed by dykes of basalt. In many cases the felspars in these basalts are pseudomorphs consisting of calcite, and the alteration has extended to the surrounding rocks with the development of various secondary minerals such as epidote. Sometimes the alteration has proceeded further with the formation of bright coloured metallic ochres and the deposition of specular iron in fissures surrounding the dykes. Lastly, the ores are found in fissures without any igneous rock, constituting real veins, but they always occur in the neighbourhood of the basaltic dykes.

Drana Kóh.

The hills called Drana Kóh (Lat. 29° 15′, Long. 61° 47′) in the neighbourhood of Zeh consist of intrusive quartz diorite. Later basaltic dykes run through this igneous mass; the intrusion of these basaltic dykes was accompanied by a considerable discharge of mineral vapours which have altered both the basalt itself and the neighbouring portion of the diorite. Veins varying in width from one foot to three feet run parallel to the dykes and contain minerals which probably resulted from the same solfataric action. These minerals are quartz and silicate of copper or "chrysocolla." The copper ore occurs in small crystals of a turquoise blue colour.

Saindak.

At Saindak, particularly in the hill called Saindak Kóh and amongst the ranges to the north-east, we find the same association of basaltic dykes and mineral veins. Only here the rocks traversed by them instead of being intrusive are sedimentary, consisting partly of volcanic tuffs and agglomerates of the flysch period, partly of shales and limestones which contain fossils indicating a middle and upper eocene age. The minerals found in the veins are principally carbonate of lime, sulphide of lead or "galena," and carbonates of copper, the green carbonate or "malachite" and the blue carbonate or "azurite". The veins are seldom more than a foot in diameter, and it is only where they are widest

that they contain galena. The carbonates of copper occur as mere incrustations. The galena is occasionally collected by the inhabitants and smelted for making shot and bullets.

Very similar veins are found at Robát Kóh and Malik-i-Siáh Kóh. Here the rocks traversed by them are principally nummulitic limestone of lower eocene age. The limestone and underlying shales are largely intruded into by great masses of diorite, but the mineral veins and also some very basic magma basalts are probably newer than the diorite. The minerals contained in the veins are mostly iron ores, carbonate of iron and hematite, occasionally associated with carbonate of copper. Hematite occurs not only in the larger veins, but in the shape of small crystals of specular iron it is found coating the fissures and planes of stratification of the limestone in the immediate neighbourhood of the dioritic intrusions.

Kóh-i-Malik-Siáh.

Amongst the recent volcanoes which rise in the western portion of the district visited, the Kóh-i-Tafdán is at the present day in the condition of a solfatara. The Kóh-i-Sultán also went through the same stage before it became finally extinct; denudation has since laid bare some large masses of rock highly altered by mineral vapours.

Products of recent volcanoes.

The masses of travertine formerly deposited by thermal springs, which are now exhausted, may also be regarded as the products of volcanic activity.

I did not visit the crater of the Kóh-i-Tafdán in Persia, but pieces of sulphur picked up upon the slopes of the volcano show that this mineral is no doubt abundant.

The mineral products of the Kóh-i-Sultán have been described in a previous chapter.

LIST OF ILLUSTRATIONS.

PLATE IV (Frontispiece).

The Kóh-i-Tafdán, seen from the north. The cliffs in deep shadow form the terminal scarp of the ash-beds of the recent volcano. The rocks in the foreground are submarine tuffs of the upper cretaceous or lower eocene period.

PLATE V.

Malik-Gat, looking south-east.

PLATE VI.

North-eastern aspect of Kóh-i-Robát.

a. Nummulitic limestone (*g* of Fig. 13).
b. Shales and sandstones (*f* of Fig. 13).
c. Nummulitic limestone (*e* of Fig. 13).
d. Intrusive sill of diorite.
e. Boundary pillar on the summit of Kóh-i-Malik-Siáh; this mountain is a boss of intrusive diorite.

PLATE VII.

Southern aspect of Kóh-i-Robát.

The tinted portion represents intrusive diorite. The hill on the bank of the river-bed in the centre of the picture consists of shales (probably eocene), capped by a fragment of a recent gravel terrace.

PLATE VIII.

Details of sections.

FIGURE 1.

Section at Tozgi.

Length of section : about half a mile.

a. Eurite.
b. Agglomerates.
c. Andesite.
d. Granophyric diorite-porphyry.
e. Agglomerates.

f. Agglomerates containing numerous blocks of nummulitic limestone.

g. Trachyte-breccia and limestones.

h. Columnar rock (augite-diorite-porphyry).

FIGURE 2.

Section across the Malik-Gat.

Length of section : about one mile.

1. Gypsiferous shales.
2. Pebble beds with volcanic fragments.
3. Limestone.
4. Shales and pebble beds.
5. Coralline limestone.

FIGURE 3.

Section north of Nushki.

Length of section : 6·86 miles.

a. Volcanic rocks of the flysch series.

b. Limestones and shales.

c. Basaltic dykes.

d. Nummulitic limestone.

e. Siwaliks.

f. Slates (probably eocene).

FIGURE 4.

Section across the Kharan hills along the Pír Puchi pass.

Length of section : 25·7 miles.

a. Augite-syenite-porphyry, western extremity of the Rás Kóh intrusion.

b. Flysch strata.

c. Nummulitic strata, principally shales with occasional limestone bands.

d. Charian range, volcanic strata of the flysch series.

e. Tertiary strata.

f. Zard spring.

g. Highly cleaved slates of tertiary age.

h. Basaltic intrusions.

i. Nummulitic limestone.
j. Hurmagai valley.
k. Limestone.
l. Jalawar village.

FIGURE 5.

Section across the Chapar range.
Length of section : 1·9 mile.

a. Olive-coloured shales.
b. Coralline limestone of Mazanen Chapar.
c. Brown limestone and tuffs.
d. Alluvium.
e. Hills at Kán.

FIGURE 6.

Section between Kishingi plain and Kardagap plain.
Length of section from east to west : 8·6 miles.

a. Plain of Kishingi.
b. Limestone band.
c. Shales in which cleavage is slightly developed.
d. Limestone band.
e. Plain of Kardagap.

FIGURE 7.

Strata of small hill at Kán.

1. Sandstones and limestone, some of them pebbly.
2. Conglomerates of volcanic material.
3. Sandstones, coarse-grained and calcareous conglomerates.
4. Red arenaceous limestone resembling a tuff.
5. Green tuff.
6. Limestone with a globular species of *Alveolina.*
7. Olive green shales.
8. Arenaceous rubbly limestone.
9. Oyster bed.
10. Purple flaggy limestone.
11. Green limestone.
12. Limestone with *Alveolina* similar to 6.

FIGURE 8.

Section across the Gat-i-Humun, near its western extremity.
Length of section: about $1\frac{1}{4}$ mile.

a. Olive green shales with gypsum.
b. Coarse volcanic tuff.
c. Thick-bedded limestone.
d. Tuff.
e. Sandstone.
f. Limestones and shales.

PLATE IX.

Details of sections.

FIGURE 9.

Section across the Kóh-i-Humai.

Length of section: about two miles and a half.

a. Hippuritic limestone.
b. Calcareous shales, calcareous sandstones, shales, etc.
c. Tuffs.
d. Columnar igneous rock.

FIGURE 10.

Diagrammatic section between Sar Kóh and Amír-Cháh.
Length of section: about 5 miles.

a. Hippuritic limestones, Sar Kóh.
b. Hippuritic limestone, Amír-Cháh.

FIGURE 11.

Khirthar strata at Saindak.
Length of section: 3,100 feet.

a. Volcanic conglomerates.
b. Thick-bedded unfossiliferous limestone.
c. Thinner-bedded fossiliferous limestone with *Nummulites granulosa*, *Micropsis venustula*, *Velates schmideliana*, etc.
d. Space hidden by *débris*.
e. Limestone with *Nummulites granulosa*, *N. spira*, *Micropsis venustula*, *Velates schmideliana*, etc.

f. Limestone with *Cerithium van-den-Heckei*, *Ovula bellardii*, etc.

g. Shales, sandstones and limestones with *Cardita*, *Corbula*, *Natica*, *Turritella*, etc. (Lower Nari).

FIGURE 12.

Section amongst the Chágai hills.
Length of section : about 3 miles.

1. Yellow calcareous rock.
2. Serpentine and epidote rocks.
3. Diabase ($\frac{13}{954}$).
4, 5, 6, 7. Diabase porphyries ($\frac{13}{955}$, $\frac{13}{956}$, $\frac{13}{957}$, $\frac{13}{958}$).
8. Rocks very much decomposed by solfataric action.
9. Diabase porphyry ($\frac{13}{959}$).
10. Granophyre ($\frac{13}{960}$).
11. Breccia basalt ($\frac{13}{961}$).
12. Balanosh Ziarat; felsites.
13. Rhyolite ($\frac{13}{962}$).
14. Quartz-felsite ($\frac{13}{963}$).

FIGURE 13.

Section of north-east slope of Robát Kóh.
Length of section: about 2 miles.

a. Recent gravels.
b. Siwaliks.
c. Tuffs, agglomerates, etc.
d. Shales with *Orbitolites*.
e. Nummulitic limestone.
f. Shales and sandstones.
g. Nummulitic limestone.

FIGURE 14.

Section at Mukak.
Length of section : 4·5 miles.
Explanation of letters in text.

FIGURE 15.

Saindak Kóh.

Length of section: about 1½ mile.

a. Tuffs, shales, etc.

b. Very coarse volcanic conglomerate.

c. Nummulitic limestone.

d. Red shales and sandstones (upper eocene).

e. Conglomerate similar to *b*, displaced along a thrust-plane.

FIGURE 16.

Section south-west of Tafui.

Length of section: 11·5 miles.

Explanation of letters in text.

FIGURE 17.

Section through Saindak.

Length of section: 19 miles.

a. Siwaliks.

b. Tuffs. (Basaltic dykes.)

c. Coarse volcanic conglomerate.

d. Nummulitic limestone.

e. Outline of Saindak Kóh.

f. Nummulitic limestone.

g. Volcanic conglomerate (the same as *c*).

h. Tuffs, sandstones, shales, etc., limestones with *Alveolina*.

i. Siah Kóh.

j. Tuffs, shales, etc., with highly developed slaty cleavage.

k. Shales and sandstones, coming in contact with the preceding rocks along an overthrust fault (see Figure 19).

l. Mirjawa plain.

FIGURE 18.

Section along the Nimik Pass.

Length of section: 12 miles.

a. Laghar Kóh (volcanic rocks).

b. Phogh Dán.

c. Tuffaceous limestones and shales.

d. Slates (probably eocene) with narrow limestone bands.
e. Limestone.
f Nummulitic limestone of Shír 'Ajab Ziárat.
g. Basaltic dykes.

FIGURE 19.

Overthrust, in the hill ranges south of Saindak.
a. Bright coloured shales, tuffs, etc., with slaty cleavage highly developed.
b. Greenish shales and sandstones without any slaty cleavage, forced over the strata (*a*) along a thrust-plane.

PLATE X.

Highly tilted tertiary slates at Zard in Kharan.

PLATE XI.

Columnar intrusive sill, near Mirjawa.

PLATE XII.

Siwaliks overlaid by recent gravels. Lar valley.

PLATE XIII.

Granitic intrusion, Kóh-i-Hanjirdán.

The higher peaks consist of intrusive rocks. The lower spurs are highly altered slates, with bands of limestone containing *nummulites*.

PLATE XIV.

Cliffs of volcanic ash-beds in the Kóh-i-Sultán.

The blocks in the foreground are fragments of a weathered lava-flow.

PLATE XV.

Kóh-i-Abú, a weathered mass of accumulated lava-flows, in the centre of the Kóh-i-Sultán. View looking east.

PLATE XVI.

Batil Kóh, a recent cone of lava rising upon the southern talus of the Kóh i-Sultán.

Map No. 1.

Geological Sketch map of the Balúchistán desert.
Scale 1″ = 16 miles.

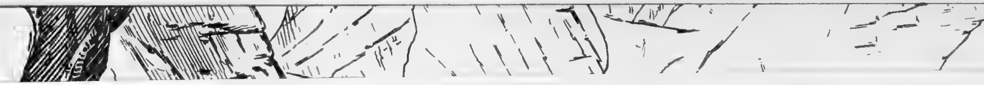
Map No. 2.

The Kóh-i-Sultán and neighbouring volcanoes.
Scale 1″ = 4 miles.

Map No. 3.

Crater Rings of the Kóh-i-Sultán.
Scale 1″ = 4 miles.

Malik Gatt, looking S. E.



Southern aspect of [illegible]

The Tinted portion represents intrusive diorite

NORTH-EASTERN ASPECT OF KOH-I-ROBAT

LOWER EOCENE STRATA.

Southern aspect of Koh-i-Robat.

The Tinted portion represents intrusive diorite

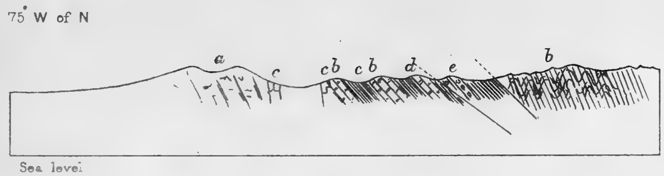
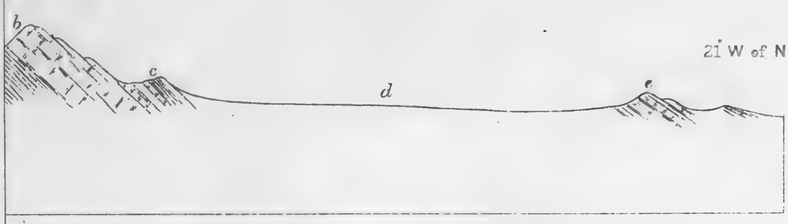


Fig. 3.



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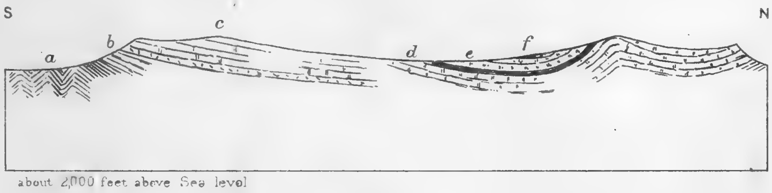
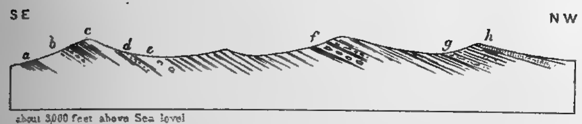


Fig. 8.

E. Vredenburg.

Memoirs, Vol. XXXI, Pl. 8.



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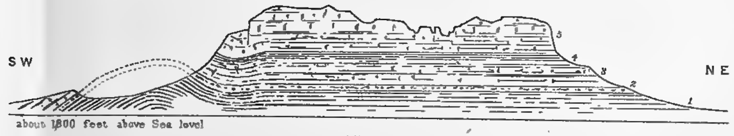

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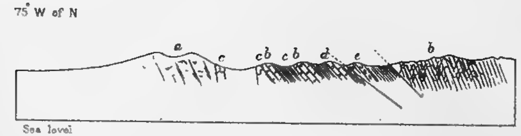

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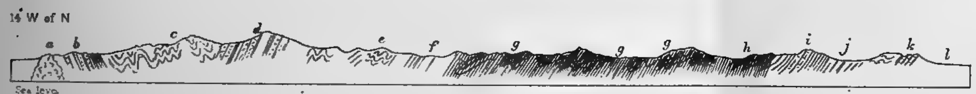

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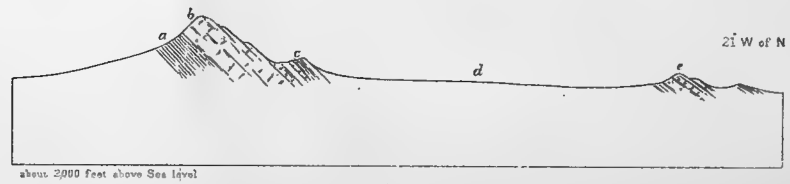

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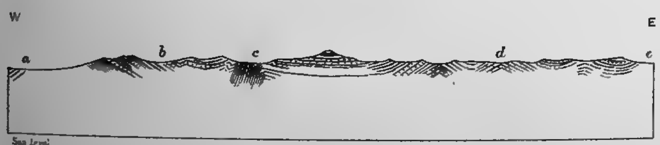

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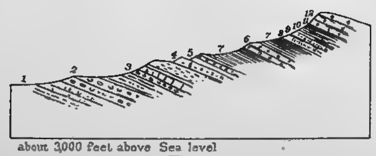

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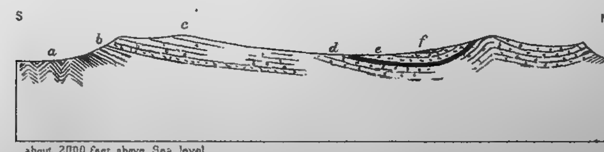


Fig. 8.

BALUCHISTAN DESERT. DETAILS OF SECTIONS.

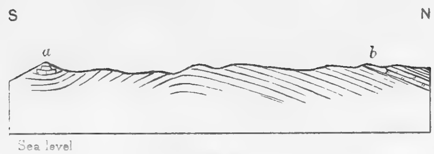


Fig. 10.

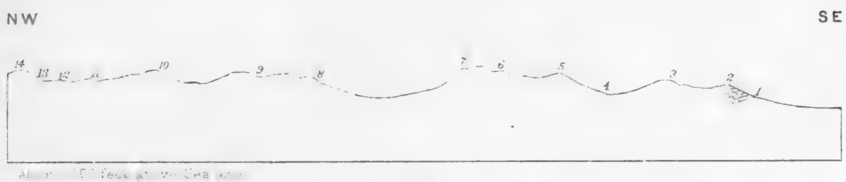
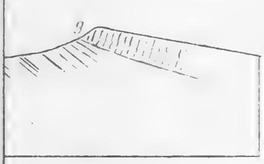
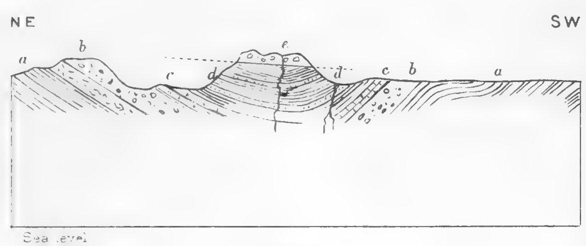


Fig. 12





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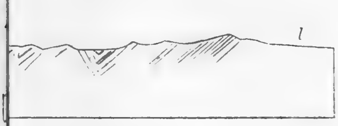


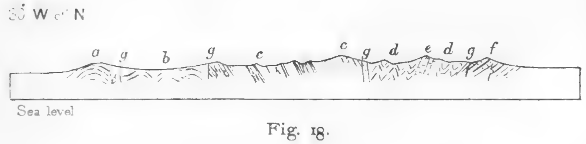


Fig. 18.

E. Vredenburg.

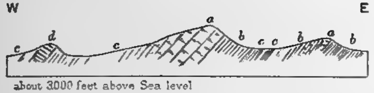


Fig. 9.

Fig. 10.

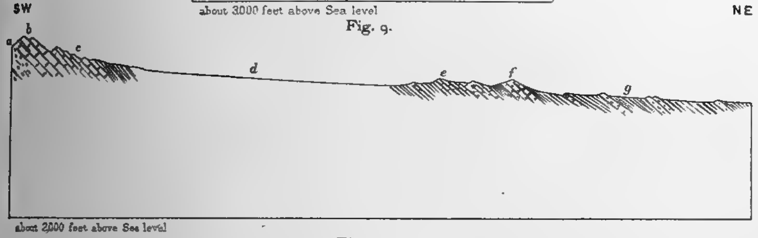


Fig. 11.


Overthrust plane near Saindak

Fig. 19.

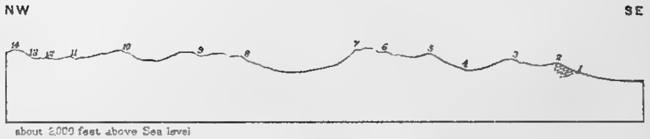


Fig. 12.

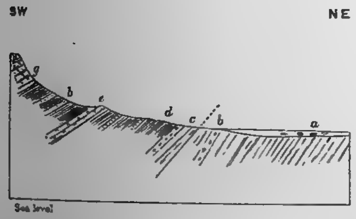
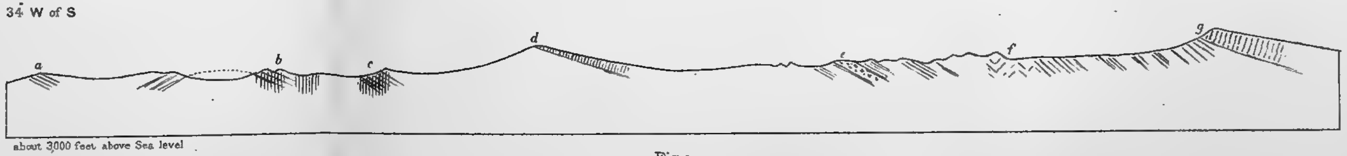


Fig. 13



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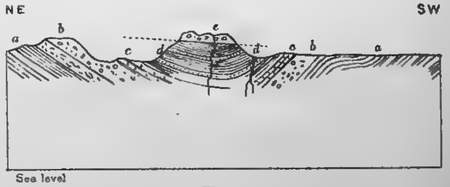

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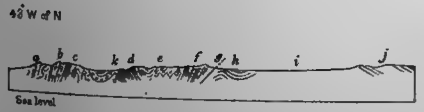

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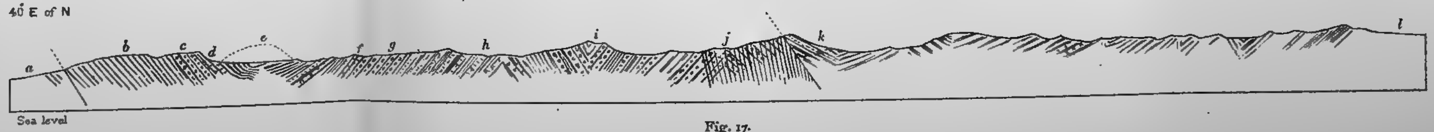

Fig. 17.

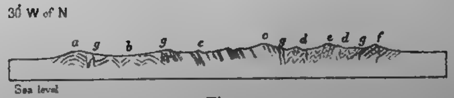

Fig. 18.

BALUCHISTAN DESERT. DETAILS OF SECTIONS.

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TERTIARY STRATA AT ZARD IN KHARAN.

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BASALTIFORM IGNEOUS ROCK AMONGST THE TUFFS NORTH OF MIRJAWA.

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SIWALIKS AND RECENT GRAVELS IN THE LAR VALLEY.

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GRANITIC INTRUSIONS IN THE KÓH-I-HANJIRDÁN.

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CLIFFS OF GAM-I-CHAH IN THE KÓH-I-SULTÁN.

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KÓH-I-'ABU.

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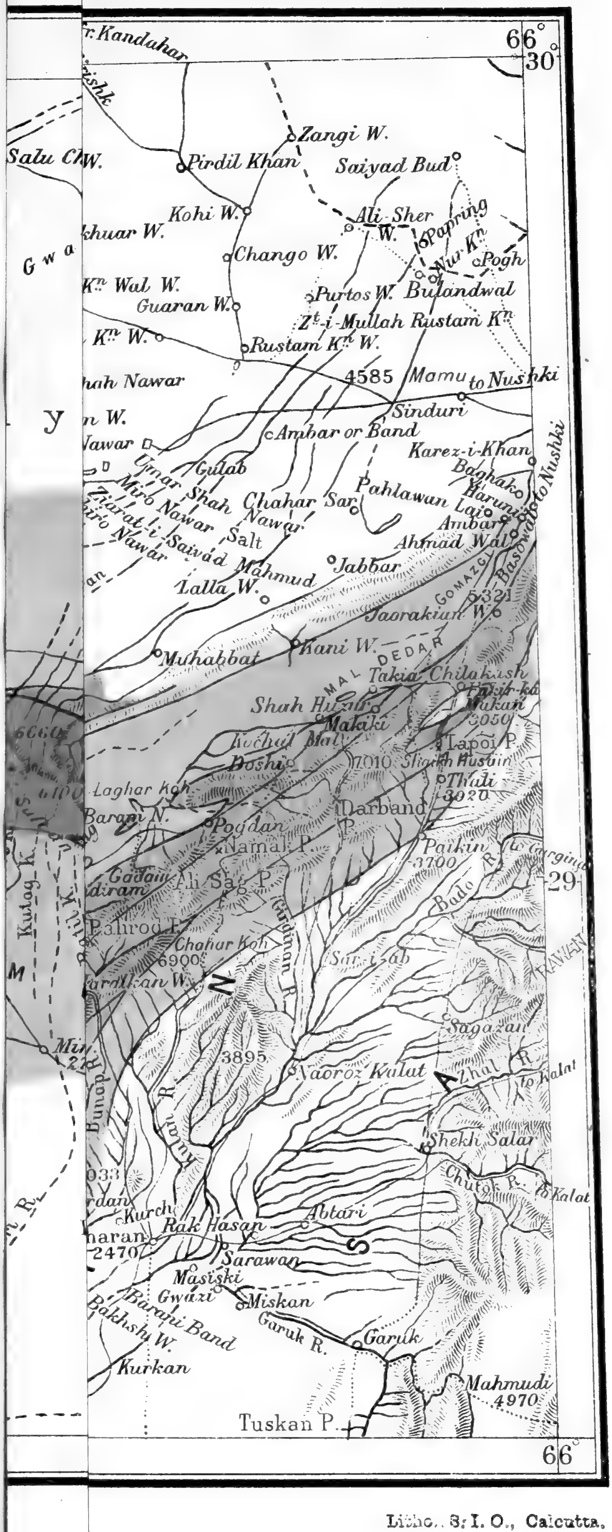
RECENT LAVA CONE OF THE BÁTIL KÓH.

GE Vol. XXXI, Part 2, Map 1.



Litho., S. I. O., Calcutta.

GEOLOGICAL SURVEY OF INDIA.

Memoirs, Vol. XXXI, Part 2, Map 1.

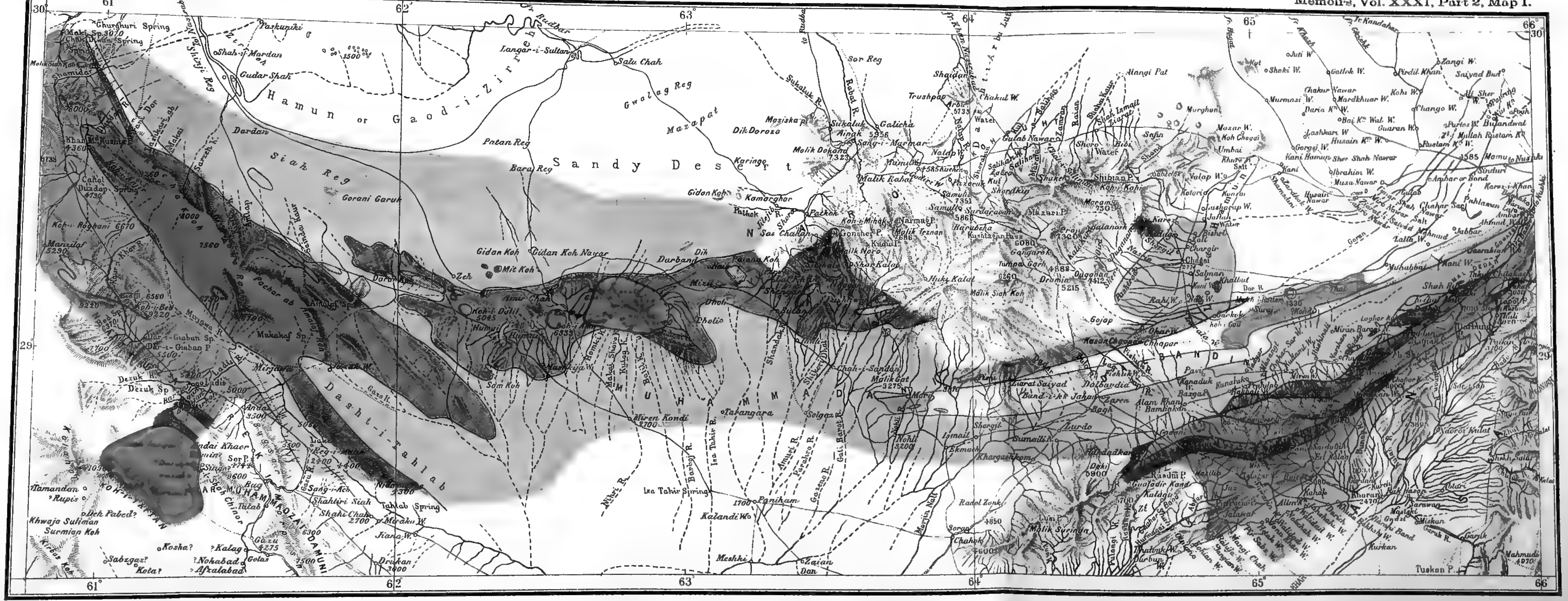
GEOLOGICAL SKETCH MAP
OF THE
BALUCHISTAN DESERT

Scale 1 Inch = 16 Miles.

Topography taken from the S. W. Section of the Map of Baluchistan, published by the Survey of India.

INDEX OF COLOURS.

- Alluvium.
- Recent volcanoes.
- Travertine.
- Siwalik.
- Khirthar.
- Ranikot.
- Cardita beaumonti beds.
- Flysch (volcanic).
- Hippuritic limestone.
- Igneous intrusions.



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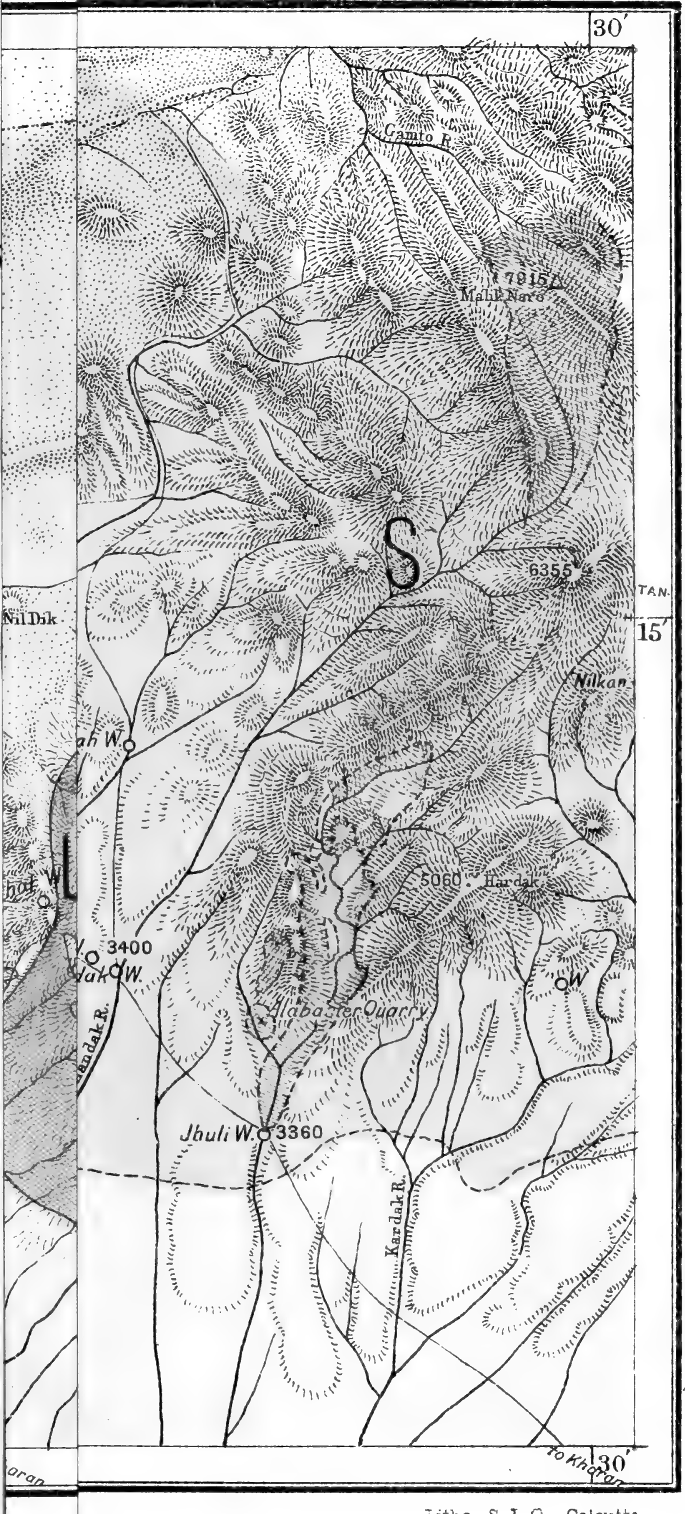


Litho., S. I. O., Calcutta.

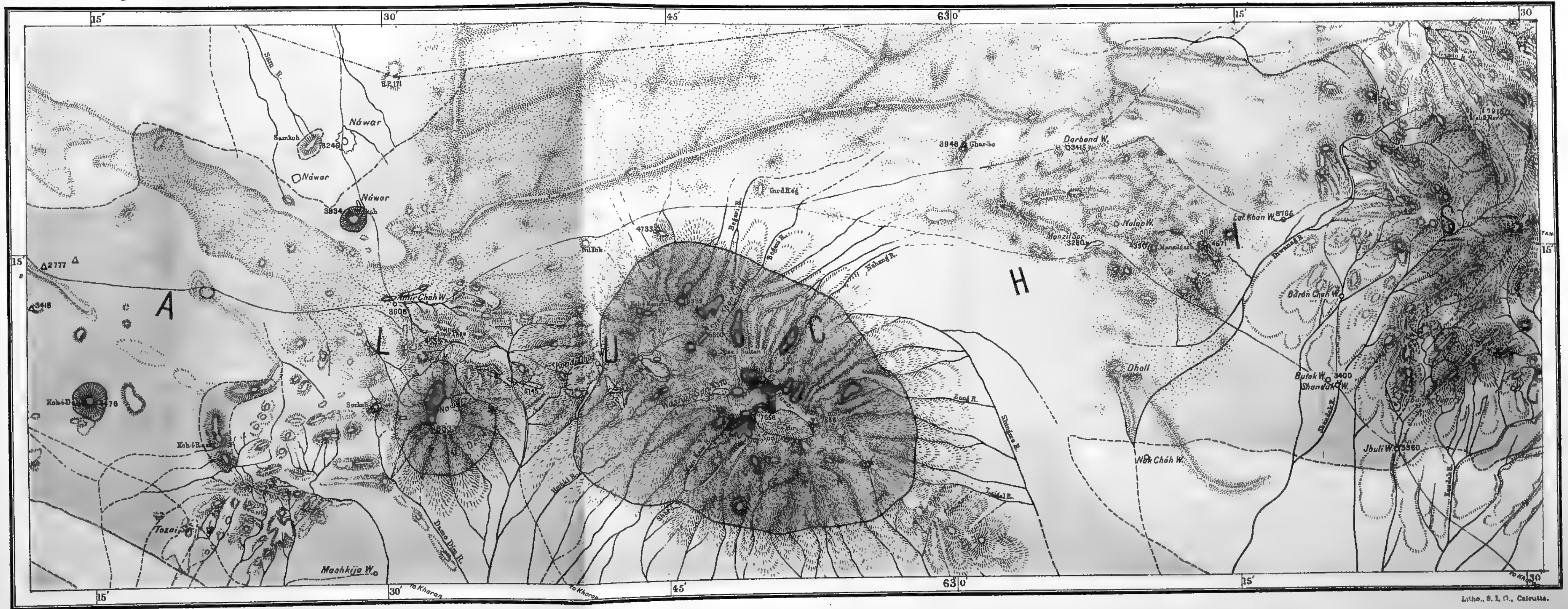
GEOLOGICAL MAP OF THE KOH-I-SULTAN AND NEIGHBOURING VOLCANOES.

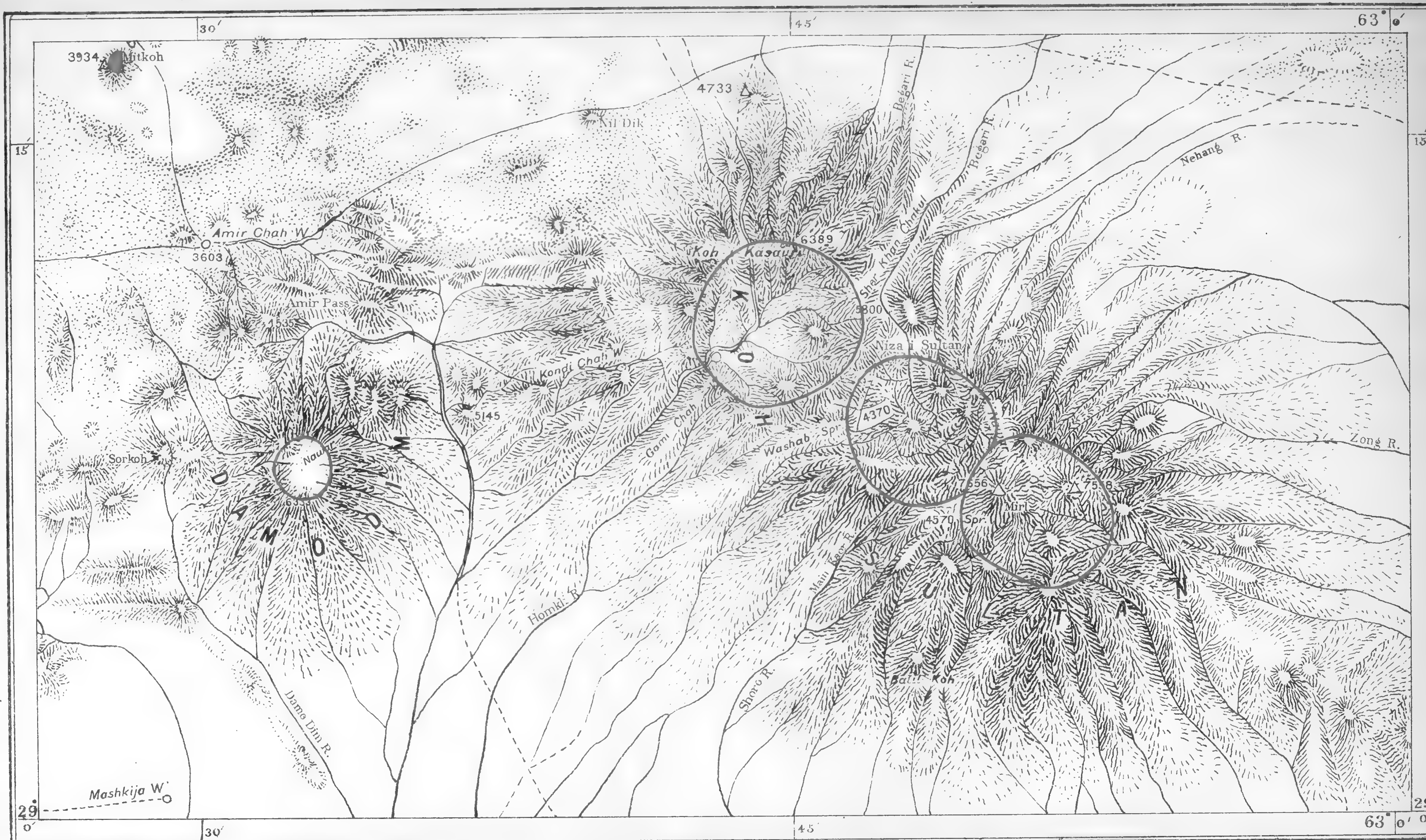
Scale 1 Inch = 4 Miles.

Topography taken from Sheet No. 14 N. E. of the North-Western Trans-Frontier Survey.

INDEX OF COLOURS.

- *Alluvium.*
- *Travertine.*
- *Lava cones.*
- *Ash-beds of Koh-i-Sultan & Domodim.*
- *Lavas of Koh-i-Abbu and Mian Koh (Koh-i-Sultan).*
- *Andesitic lavas of Koh-i-Sultan and Domodim.*
- *More basic lavas (Koh-i-Sultan).*
- *Solfataric products.*
- *Hippuritic limestone.*
- *Flysch.*
- *Intrusive rocks.*





Crater Rings of Koh-i-Sultan and Damodim

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

MEMOIRS

OF THE

GEOLOGICAL SURVEY OF INDIA.

VOL. XXXI, PART 3.

PETROLOGICAL NOTES ON SOME PERIDOTITES, SERPENTINES, GABBROS AND ASSOCIATED ROCKS FROM LADAKH, NORTH-WESTERN HIMALAYA, *by* LIEUTENANT-GENERAL C. A. MCMAHON, F.R.S., F.G.S.

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CONTENTS.

MEMOIRS

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INTRODUCTION.

The peridotites and serpentines described in the following pages are found intrusive in the tertiary volcanic series of Ladakh, North-Western Himalaya.

Some of the specimens were collected by the late Dr. Ferdinand Stoliczka, and the rest by Messrs. R. Lydekker, F.R.S., F.G.S.; R. D. Oldham, A.R.S.M., F.G.S., and T. D. La Touche, and this collection of rocks has been lent to me for description by the Geological Survey of India.

Dr. Stoliczka's reference to the rocks of the Púga valley will be found at p. 128, Vol. V, Memoirs, Geol. Surv. Ind. "These quartzose schists," Dr. Stoliczka writes, "form both sides of the Púga valley and become towards the epidote rocks somewhat chloritic, and even garnetiferous. They dip against these epidote rocks where they are visible in the eastern part of the Púga valley.

The axis of Cunningham's *Trans-Himalaya* or *Tsomoriri range* consists here of a series of *epidote*, *diallage* and *serpentine* rocks.

From their dark colours these rocks have sometimes been referred to as *basalts*, but they have certainly nothing to do with these more recent volcanic rocks. At first coming to the camp on the Púga stream we met with an epidote rock, consisting of crystallized or granular masses of *epidote*, *quartz* and *albite*. The epidote when crystallized occurs in short prisms of yellowish or bright green colour.

It is often replaced by *diallage* occurring in the same manner in short laminar prisms and forming a beautiful *syenite-like* rock. Somewhat farther to the north the epidote disappears altogether, and the *diallage* is often found disseminated through a dark green serpentine mass, and in this way forming a very peculiar rock which by many geologists, especially in the Apennines and Southern Alps, would be called *gabbro;* the Himalayan agrees exactly with the Alpine rock. *Diallage* occurs besides in large lumps, and very seldom is any *bronzite* to be seen here. The serpentine rock contains also sometimes sparingly zeolitic and felspathic minerals, and varies greatly in colour. Further to east it is occasionally to be found in serpentine-schist and purer in thin veins. In the Púga valley itself no stratification whatever is perceptible in the whole series of these last-mentioned rocks: they have a truly massive structure.

What is still remarkable and perhaps worthy of notice are large spheroidal masses of quartz, which, in addition to numerous quartz veins occur throughout the serpentine rock."

The following specimens collected by Dr. Stoliczka are described in the following pages :—

No.	94—210.*	Gabbro from the Púga valley, Ladakh.
"	94—211.	Gabbro from the Púga valley, Ladakh.
"	94—213.	Peridotite (Lherzolite), Makha river, Ladakh.
"	94—214.	Peridotite, Púga valley, Ladakh.
"	94—215.	Peridotite (Saxonite), Púga valley, Ladakh.
"	94—216.	Serpentine after picrite, Púga valley, Ladakh.
"	94—225.	Serpentine, from Hanli (Rupshu).

* The numbers given in this paper are those borne by the specimens in the Geological Survey Museum, Calcutta.

Mr. R. Lydekker's account of the "southern tertiary boundary and the large series of volcanic rocks met with along this line" will be found at pp. 111-115, Memoir of the Geology of Kashmir (Memoirs, Vol. XXII, Geol. Surv. Ind.).

"At the north-western extremity of the tertiary zone," Mr. Lydekker writes, "the purple shales of Páskim are overlain by a great mass of basaltic trap, or lava, which in this region consists of greenish anamesite, weathering to a pale-brown colour. Although there is no visible instance of the intrusion of the trap into the beds of the sedimentary rocks, yet the relations of the two are such as to indicate that the trap is the newer rock. It has, however, been already shown that trap pebbles are contained in the higher tertiaries to the south-east, and it may, therefore, be pretty safely inferred that the emission of the trap took place during some part of the time of the deposition of the tertiaries" (p. 111).

The band of trap has in places, as at Shargol, a width "as much as ten miles." It is occasionally "much mixed up" with altered tertiary sedimentary rocks, the "remnants of the sedimentary tertiaries which probably once extended continuously over the whole area, but which have been broken up and altered by the eruption of the volcanic rocks."

Mr. Lydekker traces the outcrop of the trap from point to point, but the details need not be given here; and he notes that "in the neighbourhood of Lámayúru" it is "much involved with palæozoic rocks."

"The trap in the above-mentioned area," Mr. Lydekker continues (p. 112), "has been described as composed of fine-grained anamesites, greenstones, basalts, serpentines, and a few amygdaloids and, according to Dr. Stoliczka, of gabbro and diallage rocks. No porphyritic trap occurs, and when worn, most of the pebbles acquire a dark-brown glaze."

The traps gradually die out to the westward of the Zánskar river, and the "main mass of the sedimentary tertiaries comes into direct

contact with the carboniferous rocks." "To the south-eastward of Skiu the southern tertiary boundary runs near the right bank of the Markha river" . . "In the valley of the Markha along this boundary line, numerous small masses of trap are met with, which is generally of a more crystalline structure than the trap to the westward of the Zánskar river; and it is probably pebbles of this trap which are included in the higher tertiary conglomerates. In places, as on the upper Gya river, this trap has burst through the pre-tertiary rocks, and frequently has included in itself masses of the latter crowded with crinoids. To the south-east of the Gya river the band of carboniferous rocks dies out, and the tertiaries on both their borders are in direct contact with the older crystallines. From a little to the westward of the Púga river to the extreme easterly limit of Kashmir territory, an irregularly wedge-shaped mass of the trap separates the sedimentary tertiaries from the older crystallines, and it is near the southern border of this trap that the extensive mineral deposits of the Púga valley chiefly occur" (p. 113).

At page 115, the author notes the occurrence in the Marpo ravine in the Dras valley of a "serpentine, indistinguishable from that of Páskim," which he thought might "belong to the palæozoic traps."

The following specimens collected by Mr. R. Lydekker are described in the following pages :—

No. 94—212.	Gabbro from Peak D. 24, Ladakh.
" 94—217.	Peridotite (Lherzolite) from Markha valley, Ladakh.
" 4-210.	Serpentine (Bowenite), Skiu valley, Shigar.
" 94—29.	Hornblende-rock from Ladakh.
" 94—218.	Volcanic ash from Wangat, Ladakh.
" 94—224.	Fine-grained ash from do. do.

Mr. R. D. Oldham writes as follows regarding "*The Indus Valley Tertiaries*" in the Records, Geol. Surv. Ind., Vol. XXI, p. 154 :—

"As these have already been described by Mr. Lydekker more fully than I could do, I shall confine myself to considering the conclusions that may be drawn from them.

To begin with the serpentine rocks: both Dr. Stoliczka and Mr. Lydekker speak with uncertain voice regarding their mode of origin, but both convey the impression that they form a large intrusive mass, though in both descriptions there are not wanting indications that the authors did not altogether accept this conclusion.

I crossed these rocks once on the section from Púga to Maya and again between Leh and Kashmir. In both cases I found beds of clastic origin, ashes and agglomerates interstratified with traps. To take the first named section: starting from Púga the first rock seen, after leaving the gneiss, is a serpentinous slate; this is succeeded by a conglomerate or breccia of slate and limestone, the fragments all flattened by pressure and traversed by an imperfect cleavage, and fine-grained laminated beds with fragments of rock included. The matrix of these rocks contain many small fragments of pyroxene. Further on the volcanic facies becomes more marked, and we have tuff and ashes with dense pyroxenic traps, all of which have undergone more or less complete serpentinous change.

Where the stream bends to the east, the dip of the beds, which had been northwards, changes to south, but is very obscure. At the bend of the stream a bed of limestone occurs among the volcanics, but is cut up by faults into small patches of a few yards across scattered up and down the hillside in almost perplexing manner, and this intense cutting up of the beds is sufficient to account for the absence of distinct and continuous bedding in the traps.

As to the interpretation of this section, it would at first appear that from Púga to the bend in the stream there was an ascending and below that a descending section; the crystalline limestone occupying the centre of a synclinal. But lower down-stream the same limestone occurs on the hills south of the valley above the dense traps, and to judge by the fragments brought down by streams, is overlaid by beds very like those seen in contact with the gneiss.

On the section along the Kashmir road these features are not so well seen, but even there ash-beds can be found among the traps.

So there can be but little doubt that we have here a true volcanic series.

I must not be misunderstood to deny the existence of intrusive rocks. I have myself seen these some miles south of Karzok on the Tso Morari and as far north as Shushal. Intrusive rocks doubtless occur among the volcanics, indeed this is but what might be expected and may doubtless account for the ambiguity in the two published descriptions.

As to the lithology of the beds, beyond what is implied in the above passages, nothing need be added to the descriptions of Dr. Stoliczka, Mr. Lydekker, and later of Colonel McMahon."

The microscopical examination of the following specimens collected by Mr. R. D. Oldham are described in this paper, *viz.* :—

No.	8—278.	Lherzolite from the Púga valley, Ladakh.
"	8—276.	Serpentine after Troctolite, Púga valley, Ladakh.
"	8—279.	Porphyritic diorite, from N. of Chang La, Ladakh.
"	8—280.	Porphyritic diorite. Junction of Chang and Inchine valleys, Ladakh.
"	8—281.	Porphyritic diorite. Junction of Chang and Inchine valleys, Ladakh.
"	8—271.	Volcanic ash, from the Púga valley, Ladakh.
"	8—272.	Volcanic ash, from do. do.
"	8—275.	Volcanic ash, from do. do.

The following specimens collected by Mr. T. D. La Touche are also described :—

No.	8—293.	Serpentine from valley W. of Sirsa La, Zánskar.
"	8—294.	Serpentine from do. do.

The second edition of Medlicott and Blanford's Manual of the Geology of India by Mr. R. D. Oldham contains at page 346 the following reference to the Ladakh igneous and volcanic rocks :—

"In the sections eastwards of Leh, conglomerates are said to occur near the upper limit of the series, and these conglomerates contain pebbles of the volcanic beds, which will presently be described, and of nummulitic limestone. The occurrence of these last shows that the beds had locally been elevated and exposed to

denudation, while elsewhere the process of deposition was going on continuously.

In the central portion of the exposure the sedimentary beds are in direct contact with the older rocks along their south-western margin, but at either extremity they are separated by a great series of volcanic rocks of a very basic type. There can be no doubt that these rocks, which form the upper limit of the tertiary system of this region, are in the main contemporaneous eruptive products, as they include beds of volcanic ash and agglomerate,[1] but there are also numerous intrusive masses associated with the bedded traps. Basic trappean intrusions are also found in the pre-tertiary rocks south-west of the boundary, which are evidently connected with these same eruptive rocks. These intrusions are interesting as, at Púga and in the Markha valley south of Leh, they are composed of peridotite, until lately the only recorded instances of ultra-basic rocks having been found in India."[2]

The microscopical examination of the specimens enumerated above shows that many of them are ultra-basic peridotites, and others are serpentines formed by the more or less complete alteration of olivine rocks. Both groups belong to the plutonic class of igneous rocks; their structure is completely holo-crystalline, and they have never flowed out on the surface of the earth as lavas. The same remark applies to the gabbros.

The association of these holo-crystalline plutonic rocks with volcanic beds of lava and ash, as in the Púga valley, must be purely accidental. The holo-crystalline igneous rocks are evidently, as suggested by Mr. Oldham, intrusive in the volcanic series, and may possibly have no direct genetic relation to them. It is quite a common feature in Himalayan geology to find diverse igneous rocks following each other along the same planes of weakness.

As will be seen from my detailed description of the porphyritic diorite collected by Mr. Oldham (which was not found *in situ*),

[1] C. A. McMahon, Records, XIX, p. 118 (1885); R. D. Oldham, Records, XXI, p. 154 (1888).

[2] C. A. McMahon, Records, XIX, p. 115 (1885).

I regard this rock as a hypogene representative of a volcanic rock rather than a volcanic rock itself. The hornblende-rock, said to be an altered pyroxenite, is also a hypogene rock. It is doubtful whether any of the rock specimens described in this paper include a true lava.

The samples of ash sent me are from the Wangat and Púga valleys. As these rocks have been much altered by the combined effects of pressure, aqueous infiltration, and the contact action of intrusive igneous masses, it is in some cases difficult to say decidedly whether one is dealing with an altered ash, or a metamorphosed lava: and, in other cases, whether the rock is an ash or a very fine-grained fragmentary rock containing some splintery pieces of acid lavas, such as felsites and rhyolites.

One of the serpentines from Shigar (4—210) collected by Mr. Lydekker is of especial interest as it proves to be the rare variety called bowenite or pseudo-jade. The description of this rock is given at page 11.

Peridotites.

No. 8—278. Peridotite (Lherzolite) from the Púga valley, Ladakh; collected by R. D. Oldham, F.G.S.; Sp. G. 2·865.

This is a much altered rock composed of olivine, monoclinic pyroxene, a little enstatite, bastite, diallage, grains of magnetite, and secondary decomposition products.

The olivine is traversed by very numerous canals of serpentine and is cut up into rounded grains.

The pyroxene has also suffered much from decomposition. It is dull and polarizes very feebly. Like the olivine it is penetrated by infiltration canals, but they are not so numerous as those in the former mineral. They are filled with a colourless serpentinous mineral inert in polarized light. The diallage and bastite possess hardly any double refraction.

The olivine grains are sometimes fringed with radiating tufts of fine needles, with oblique extinction, which are evidently some form

of amphibole. Isotropic structureless mineral matter often intervenes between the serpentine proper and the pyroxene and bastite. I think it is identical with that stopping the canals in the pyroxene and is a variety of serpentine.

No. 94—213. Altered Peridotite (Lherzolite) from the Markha river, Ladakh; collected by the late Dr. Ferdinand Stoliczka; Sp. G. 3·155.

This specimen has already been described by me in the Records, Geol. Surv. Ind., Vol. XIX, p. 117, and I quoted in that paper Dr. Stoliczka's and Mr. Lydekker's references to it in the Mem., Geol. Surv. Ind., Vols. V, p. 343, and XXII, p. 107, from which it appears that it is intrusive in rocks of eocene age.

This peridotite is composed of olivine, enstatite, augite, picotite and magnetite. Olivine is very abundant, the major part of the rock consisting of it. Fine aqueous canals traverse it in all directions, but beyond the formation of these channels serpentinisation has made no progress and has left the body of the mineral quite fresh. The augite and enstatite, on the other hand, exhibit the commencement of the first stages of conversion into diallage and bastite.

Cracks in the rock are stopped with a colourless fibrous serpentine.

No. 94—214. Altered Peridotite, from Púga valley, Ladakh; collected by the late Dr. Ferdinand Stoliczka; Sp. G. 3·039.

This rock consists of serpentine and diallage with a considerable amount of secondary magnetite. The serpentine and diallage present their usual characters and do not need detailed description. Serpentine is the most abundant mineral, but diallage does not fall very far behind it.

No. 94—215. Partially altered Peridotite (saxonite) from the Púga valley, Ladakh; collected by the late Dr. Ferdinand Stoliczka; Sp. G. 2·857.

This rock was described by me in the Records, Geol. Surv. Ind., Vol. XIX, p. 115. It is composed of olivine, serpentine, enstatite, pyroxene and picotite.

Olivine constituted the major part of the original rock. The proportion of fresh olivine to serpentine in the hand-specimen examined varies very much. In places olivine preponderates and the field of the microscope consists of fresh olivine traversed by a network of narrow canals filled with serpentine. In other places the field consists of serpentine with small remnants of unaltered olivine left in it here and there.

The enstatite is colourless and polarizes feebly. It is cut up by canals of serpentine and has evidently sustained considerable strain and pressure. The lamellæ are sometimes bent and strain shadows are not uncommon. Some of the slices exhibit a lamellar intergrowth of monoclinic pyroxene and enstatite similar to that described by Rosenbusch.[1] They can only be distinguished from each other in polarized light.

The slices also contain some allo-triomorphic crystals of pyroxene and some picotite. The structure of the rock is holo-crystalline.

No. 94—217. Peridotite (Lherzolite) from Markha valley, Ladakh; collected by R. Lydekker, F.R.S.; Sp. G. 2·976.

This rock is composed of olivine, enstatite, augite and picotite. Olivine is by far the most abundant mineral and enstatite comes next.

The olivine is traversed by a perfect net-work of serpentine canals, but is otherwise quite fresh. The enstatite has also suffered to some extent in this way, but not so much as the olivine. Both the enstatite and the augite are nearly colourless in transmitted light.

The structure of the rock is holo-crystalline.

SERPENTINES.

No. 4—210. Serpentine, species Bowenite, from the Skiu valley, Shigar; collected by R. Lydekker, F.R.S.

Mr. Lydekker in his Memoir on the Geology of Kashmir (Memoirs, Geol. Surv. Ind., Vol. XXII), at page 189 refers to this serpentine as follows:—" In these shaly rocks (of carboniferous age) somewhere

[1] Microscopical Physiography of the rock-making minerals, by Rosenbusch. Translated by Iddings; p. 205.

high up on the peak named Mango-Gusor (20,635 feet) there occurs a greenish-yellow calcareous serpentine, fragments of which are found fallen into the ravines below. This rock, which appears to be similar to the one from the presumed Kuling series of the upper Wardwan valley, is extensively sought by the Shigar people for the manufacturing of small cups, etc., and will be further alluded to in the chapter on economic geology."

The occurrence of the rock in the upper Wardwan valley is referred to at page 150 of the Memoir as follows:—"Between the pass and Rangmarg, in the upper Wardwan valley, there occurs on the right bank of the river another mass of the same granitoid-gneiss, overlain to the south and west by dark slates and the characteristic supra-Kuling rocks. These slates contain bands of a greenish serpentinous rock identical with a similar rock underlying the supra-Kuling series of Shigar, and it is accordingly presumed that these rocks are the partially altered Kuling series."

The passage in the chapter on economic geology alluded to in the extract given above is as follows:—"From a calcareous serpentine or verd antique occurring in the (probably) Kuling rocks of the neighbourhood cups and small vases are extensively manufactured at Shigar, in Baltistan. The rock is locally known as yesham, or jade, and is of bright apple-green colour, sometimes shading off to yellow, or bottle-green. A specimen of one of these cups, presented by the present writer, is in the Indian Museum and another presented by Mr. Drew, in the Geological Museum, Jermyn Street." (Memoirs, Geol. Surv. Ind., Vol. XXII, p. 339.)

The hand-specimen in the Calcutta Museum, No. 4-210, is coloured on the weathered surface a dull greenish-yellow inclining, on freshly broken faces, to a pale sulphur yellow. Its specific gravity is 2·48[1] and its hardness 5.

In order to compare the rock with the typical bowenite from

[1] I am responsible for this determination and for the specific gravity of Nos. 8—280 and 8—294. I operated on pieces of suitable size with the aid of a Chemical balance. The Sp. G. of the other specimens was determined in the Geological Survey Office, Calcutta.

Afghánistán described by me in the Mineralogical Magazine, Vol. IX, p. 187, I have made an analysis of the Shigar rock, which I give below (No. I) side by side with that of the Afghán bowenite made by Mr. G. T. Prior, M.A., F.G.S., F.C.S., of the Mineralogical Department of the British Museum :—

	No. I, from Shigar.	No. II, from Afghánistán.
Silica	41·13	44·73
Magnesia	43·65	42·64
Alumina	1·23	0·32
Iron	1·49	0·33
Lime	·17	trace
Manganese	...	...
Water	12·46	12·21
Total	100·13	100·23
Sp G.	2·48	2·59
H.	5·0	5·0

It will be seen from the above that both rocks are substantially the same in composition. In both the hardness is considerably in excess of ordinary serpentine.

None of the specimens of the Afghán mineral that I have seen have the peculiar sulphur-yellow colour of the Shigar rock. On the contrary they vary from a dark greenish-grey to pale sea-green mottled with white and apple-green. Mr. Lydekker did not see any of the Shigar bowenite *in situ*. His specimens had fallen from the Mango-Gusor peak and were picked up in the ravines at its foot. All the blocks from this locality appear to have been of yellow colour. Mr. Lydekker saw, however, the apple-green variety at Shigar to which place it is brought in order to be made into cups. He did not see it *in situ*, but doubtless it is found somewhere in the neighbourhood. The apple-green variety, Mr. Lydekker states, sometimes shades into yellow or bottle-green.

I trust that some future explorer will find the actual outcrop of bowenite and ascertain its exact mode of occurrence. Is it in dykes, sills or in veins? Does the apple-green variety shade off into the sulphur-yellow variety or do they form distinct outcrops? In what

rocks does it appear and at what period did the intrusion of bowenite take place?

Under the microscope thin slices of the Shigar bowenite, when viewed between crossed Nicols, exhibit scattered specks of doubly refracting mineral matter on a dark back-ground very suggestive of a star-spangled sky on a clear dark night. On revolving the Nicols the bright points become dark and the dark ones bright. The slices contain no isotropic matter except in veins.

The doubly refracting particles are of microscopic size and are without a trace of crystalline form.

Thin slices contain small granules of magnetite, and are dotted over with irregular opaque spots, white in reflected light, the exact mineral character of which is uncertain. Some of the serpentine occurs in strings having a transverse fibrous structure.

The double refraction of the serpentine in the Shigar bowenite is low. It possesses straight extinction. The character of the depolarization is positive, and its refraction lies between 1·560 and 1·606.

The microscopic examination of thin slices does not afford any clue as to the nature of the original minerals out of which the serpentine was formed. All original structures have been obliterated. Even "the curved feathery and sheaf-like crystals," seen in the bowenite of Afghánistán, and which I referred to olivine as their parent, are absent in the Shigar rock.

I give for comparison reproductions of photographs of thin slices of the two rocks as seen under the microscope between crossed Nicols: *viz.*, fig. 1, Pl. 17, Shigar bowenite; figs. 2 and 3 small and large grained Afghán bowenite.

No. 8—276. Serpentine after a troctolite inclining towards picrite, from Púga valley, Ladakh; collected by R. D. Oldham, F.G.S.; Sp. G. 2·785.

The hand-specimen is a dark greenish-grey compact rock spotted with white.

[1] Nothing is known about the mode of occurrence of the Afghán bowenite.

The original rock appears to have been a holo-crystalline mixture of olivine, monoclinic pyroxene, and labradorite, the olivine largely predominating. The olivine has been almost wholly transformed into serpentine, pale yellow in transmitted light. It exhibits the usual mesh-structure in polarized light, and eyes of unaltered olivine are visible here and there. Marginal deposits of magnetite are abundant as in normal serpentine.

The pyroxene and labradorite are both allo-triomorphic. The pyroxene is very highly altered and steatitic. In only one slice, No. 1994 of the Calcutta Geological Museum microscope slides taken from No. 8-277, is any of the pyroxene at all fresh. The labradorite exhibits multiple twinning, the maximum extinction being $28\frac{1}{2}°$. Some of the felspar is traversed by fine infiltration canals which have penetrated into it from the serpentine.

The hardness (4) and Sp. G. of the rock are both rather high for serpentine.

No. 8—293. Serpentine, from the valley west of Sirsa La; collected by T. D. LaTouche; Sp. G. 2·638.

The bulk of this rock is made up of serpentine after olivine. The conversion of the latter mineral has been complete and no eyes of olivine have been left in the serpentine. The thin slices examined also contain remnants of augite, a finely fibrous serpentine, picotite and some magnetite. The pyroxene fragments are mere remnants of large crystals, the major portions of which have been converted into serpentine by aqueous agents. The augite exhibits a single cleavage, and in some cases the angle of extinction measured from that cleavage is as low as from 6° to 11°. This may be due to partial uralization.

The only mineral that calls for any comment is the finely fibrous serpentine. It is rather suggestive of bastite, but as it has evidently been derived from augite and not from enstatite, it cannot be referred to that mineral. It is almost colourless in thin sections, it has

a feeble double refraction and has the refractive index of serpentine. In converging polarized light I could get no definite results even with a $\frac{1}{12}$ immersion lens in oil. This fibrous serpentine generally surrounds remnants of corroded augites and is evidently the product of the decomposition of large crystals of this mineral. (Figs. 4 and 5, Plate 18.) This conclusion is confirmed by two observations. The first is that a large augite (Fig. 5, Plate 18) is penetrated by solution veins which are now filled with the fibrous serpentine and this is continuous with the fibrous serpentine in which the augite is imbedded. The veins widen out towards the margin of the augite like the mouths of rivers, and the fibrous serpentine in them passes into the fibrous serpentine outside without a break of any kind. The second fact is that though the fibrous serpentine has generally straight extinction, I have observed one or two cases in which the extinction is oblique. The latter fact seems to indicate that the serpentine was derived from a monoclinic pyroxene, but that its conversion in some cases was not quite complete.

This fibrous serpentine is I think a variety of chrysotile.

No. 82—94. Serpentine, from the valley west of Sirsa La, Zánskar; collected by T. D. La Touche.

The two hand-specimens consist of serpentine with a vein of white soda-zoisite running through it.

The dark portions of the hand-specimens are composed of serpentine with allo-triomorphic crystals of enstatite and magnetite imbededed in it. No eyes of olivine remain.

The following note was made by Mr. F. R. Mallet, F.G.S., F.C.S., in the Calcutta Geological Survey Laboratory book, p. 129, under date 19th January, 1889:—

"Sp. G. 3·442 (Mr. Blyth)
H. 7.

Fuses easily to a blebby bead with strong intumescence. When treated for two and a half hours with strong hydrochloric acid 61·2

per cent. was dissolved (Mr. Blyth). After ignition gelatinizes with hydrochloric acid.

Contains abundant silica, alumina and lime, a very little iron, magnesia, soda, and a little water.

In all the above characters the mineral agrees with *zoisite*, except that it is decomposed (without ignition) by hydrochloric acid. A specimen of zoisite from Valtigl, Tyrol (M. 1639) when heated in hydrochloric acid for 2½ hours had 10·41 per cent. dissolved. After heating for 2½ hours in strong sulphuric acid 8·4 per cent. only was dissolved of I-177," [*viz.*, the white mineral in 8-294 under consideration. New numbers seem to have been given to the specimens after their transfer to the Geological Museum.]

The specific gravity 3·442 and hardness of 7, alluded to above, appears to refer to the white mineral (zoisite) and not to the rock specimen as a whole. I found the Sp. G. of the serpentine to be 2·67, and the zoisite 3·483, which latter corresponds very closely to Mr. Blyth's figures. I operated on a small piece with the aid of a chemical balance. Dana gives the Sp. G. for "ordinary" zoisite as 3·226 to 3·381 (Text-book of Mineralogy by E. S. Dana, 1898, p. 438). The slight increase in the Sp. G. of the Zánskar mineral is doubtless due to the presence of the oxide of iron, numerous dots of which are to be seen in thin slices under the microscope.

Some would probably call the mineral under consideration saussurite and the term would not be inappropriate. Dana puts the hardness of saussurite as 6·5 to 7 and the Sp. G. as ranging from 3 to 3·4 (System, 6th Ed., 1892, p. 515). "In composition it often approaches zoisite, of which it has been regarded as a soda-bearing variety."

As the name saussurite appears to be given to minerals which differ much from each other and as "it is rarely, if ever," Dana states, "a homogeneous mineral," I think it will be best to call the white substance in the vein running through the Zánskar serpentine

a soda-zoisite. Its optical characters agree with zoisite. Part of it is clear and transparent, but here and there it is clouded and opaque. Its double refraction is feeble, and often it has no action on polarized light. Its refraction is high, namely, higher than 1·630, and lower than 1·740. The refraction of zoisite ranges from 1·696 to 1·702.

No. 94—216. Serpentine after picrite from Púga valley, Ladakh ; collected by the late Dr. Ferdinand Stoliczka ; Sp. G. 2·825.

This rock is composed of serpentine, olivine, augite, and felspar ; the first named being the most and the felspar the least abundant mineral.

The serpentine contains eyes of olivine, and exhibits the usual mesh-structure and other characteristics of serpentine derived from that mineral. The infiltration-canals running through it are, as usual in olivine-serpentine, lined with banks of magnetite thrown down as a chemical deposit in the course of the decomposition of the olivine and the formation of the serpentine.

The augite is colourless in transmitted light and is probably malacolite or an allied species. It rarely exhibits decided cleavage, but when it does, it is a close, single cleavage resembling that of diallage. It is traversed by occasional canals of serpentine ; but as usual in such cases, the pyroxene has not yielded as readily to aqueous agents as the olivine.

The felspar is much decomposed, but it shows the albite twinning of plagioclase. Judging from the angles of extinction (the highest obtained in suitable cases was 25°) and from the fact that it contains infiltration-canals, it appears to belong to the labradorite species.

No. 94—225. Serpentine, from Hanli (Rupshu) ; collected by the late Dr. Ferdinand Stoliczka ; Sp. G. 2·604.

This is an ordinary serpentine rock. It exhibits the usual mesh-structure, and is composed of the minerals serpentine, magnetite and

titaniferous iron. It also contains ferric oxide. The hand-specimen has a slicken-sided appearance and under the microscope the rock is seen to have been subjected to pressure, shearing, and here and there to contortion.

GABBROS.

No. 94—210. Gabbro; collected by the late Dr. Ferdinand Stoliczka, in the Púga valley, Ladakh ; Sp. G. 3·076.

When examined under the microscope this rock is seen to be composed of augite, diallage and saussurized plagioclase.

Nearly the whole of the augite has been converted into diallage and only portions of the crystals have escaped change. Both minerals polarize brilliantly in colours of Newton's second order. They contain tabular allo-triomorphic patches of brown hornblende rather suggestive of biotite. The pleochroism of the hornblende is somewhat feeble; and between crossed Nicols it changes from a dark blackish-grey to a pale orange-yellow of the first order. It shows no cleavage. With convergent polarized light it gives a biaxial bar. It looks like a secondary product of decomposition.

The felspar—an altered plagioclase—has been more or less metamorphosed into zoisite. In hardness it is about 6·5 of Mohs' scale. A chip of it sank in cadmium boro-tungstate, its specific gravity is therefore greater than 3·28. This agrees well with zoisite, which has a hardness of 6 to 6·5 and a specific gravity of from 3·226 to 3·381.

Between crossed Nicols the zoisitic felspar ranged from a feeble yellowish white of the first order to isotropic.

The structure of the rock is holo-crystalline.

No. 94—211. Gabbro; collected by the late Dr. Ferdinand Stoliczka, in the Púga valley, Ladakh ; Sp. G. 2·959.

This rock is a holo-crystalline mixture of diallage and labradorite felspar.

The diallage is very typically developed. It usually polarizes brilliantly in colours of Newton's first order. Here and there it has suffered alteration to hornblende and in other places into zoisite.

The felspar, judging from the angle of extinction from the twinning plane of albite twins, is labradorite. The maximum extinction in five suitable cases was $33\frac{1}{2}^{\circ}$. It has suffered more or less conversion into zoisite, the change being partial in some cases but complete in others.

No. 94—212. ***Gabbro,*** from Peak D. 24, Ladakh ; collected by R. Lydekker, F.R.S., F.G.S.; Sp. G. 3·195.

This rock is composed of olivine and diallage with some picotite, the first mentioned mineral predominating.

The olivine is fairly fresh and polarizes brilliantly in the blue, red, and yellow of Newton's second order. It is traversed by some aqueous canals but serpentinisation has hardly commenced.

The diallage, on the other hand, is extremely dull between crossed Nicols and polarizes feebly in shades of grey.

The rock has evidently sustained considerable pressure. The olivine is much cracked, and here and there puts on a micro-tessellated structure imitative of the tessellated quartz of the Himalayan granites. Both the olivine and the diallage exhibit strain shadows. Some of the latter also show an interrupted foliation distinct from the fine cleavage.

PORPHYRITIC DIORITE.

Collected by R. D. Oldham, A.R.S.M., F.G.S.

No. 8—279. Locality, 2 miles North-East of Isul Tak, North of Chang La, Ladakh.

No. 8—280. Locality, junction of the Chang and Inchine valleys, Ladakh.

No. 8—281. Locality, junction of the Chang and Inchine valleys, Ladakh.

The above specimens are all samples of identically the same rock and it will be convenient to describe them together.

The matrix appears to the unaided eye to be compact in structure and varies from a dark slaty to a dark greenish-grey.

The porphyritic felspars are in thin tabular crystals, the face b (010) forming the platy surface. They sometimes attain a length of 4 centimetres and their average width is about 2, and their thickness from 0·2 to 0·4 centimetres. Owing to traction, or pressure, whilst the rock was in a plastic condition, the b (010) faces are generally in the same plane, so that when the fractured surface of the hand-specimen coincides with that plane, platy crystals only are seen. On the other hand, when the fractured surface of the specimen is at right angles to that plane, only slender, lath-shaped crystals are visible. Both these features are well seen in the hand-specimen 8—281.

The porphyritic felspars, judging from the extinctions measured from the twinning plane in suitable cases, and other features, belong mainly to the labradorite species, though a little andesine appears to be also present. The labradorite belongs to the most acid variety, the highest extinction angle obtained not exceeding 26°.

The orientation of the large felspars is generally speaking approximately parallel, but here and there they locally radiate at various angles up to 90° from this general direction, indicating the existence of local variation in the effects of traction on the flow of the viscid uncooled mass prior to consolidation.

The microscopical examination of thin slices shows that many of the porphyritic felspars possess zonal structure. They have sometimes been cracked and shattered internally and contain marginal inclusions of the magma, which also penetrated them in the form of tongues. The cracks are sometimes filled with chlorite and sometimes with a structureless isotropic substance, which is probably allied to zoisite. Portions of the felspars, in some cases, are fairly fresh. Other crystals are much corroded and some have almost become pseudomorphs of chlorite and zoisite.

The groundmass is composed of allo-triomorphic hornblende, felspar prisms, and iron ores, namely, magnetite, ilmenite, pyrite and limonite.

The hornblende is pleochroic in shades of green and greenish-yellow. It rarely exhibits any cleavage; and it is not at all fresh. It polarizes sometimes in colours of Newton's first order, but a change into chlorite had evidently begun, and had made progress in some individuals. It, or the augite from which it was derived, was evidently one of the last minerals to crystallise out of the cooling magma, for it is micro-poikilitic and generally encloses several small felspars wholly, or partially, within its crystals. Occasionally the amphibole exhibits a tendency to become idiomorphic, but never shows decided crystallographic outlines.

The second generation of felspars vary very much in size, but one that may be considered a fair average specimen measured 0·035 millimetres long by 0·0063 thick. The small felspars alluded to as the second generation, are all either in binary or multiple twins. The extinctions in those intermediate between the microliths and large porphyritic felspars range from $16\frac{1}{2}$ to $20\frac{1}{2}$ degrees; and the microliths from 0° up to $22\frac{1}{2}^\circ$. Those extinguishing from 0° to 6° are probably oligoclase and the others acid labradorite with some andesine or albite.

None of the above three specimens were found *in situ*, but came from blocks in recent deposits. I described[1] a porphyritic volcanic rock under the name of basalt-porphyry from the ridge above Bhandal, in the Chamba territory on the borders of the Kashmir State, which, macroscopically considered, very much resembles the rocks under consideration. The basalt-porphyry exhibits porphyritic plagioclase felspars starred about in a dark-grey compact matrix, which under the microscope is seen to be a matted mass of felspar microliths in a finely granular base or groundmass. The specific gravity of the Bhandal rock averaged 2·89; that of

[1] Rec. Geol. Surv. Ind., Vol. XVIII, p. 96.

No. 8—280, determined with the aid of a chemical balance, was 2·90. Very possibly the porphyritic diorite of Ladakh may be the hypogene representative of some such volcanic rock as the Bhandal porphyrite and its hornblende may be paramorphic after augite.

94—29. *Hornblende-rock*, from Ladakh; collected by R. Lydekker, F.R.S., F.G.S.; Sp. G. 3·095.

This is entered in the list as a "Pyroxenite almost completely changed to hornblende-rock." This short description is doubtless correct and may be based on observations in the field. The rock is said to be of pre-silurian age.

Under the miscroscope the thin slices are seen to be composed of hornblende with some magnetite. The hornblende is in shapeless crystals or grains. In transmitted light and in thin slices it varies from colourless to a pale sage-green and pale blue-green. A single cleavage is sometimes well developed, but it is generally very imperfect. This is crossed by transverse cracks which are inconstant in direction. The angle at which these cracks cross the first cleavage sometimes suggests the cross-cleavage of augite and sometimes that of hornblende. Pleochroism is not strong and the changes are from pale yellowish-brown to a pale brown-green. The angle of extinction varies from 15° to 39°. Between crossed Nicols some sections are very dull, but some polarize rather brilliantly in the blue, yellow and red of Newton's first order.

The hornblende is not at all fresh, and alteration to zoisite has been more or less set up.

There are also here and there nests of an almost colourless mica. It is evidently a secondary product.

Van Hise[1] has shown that both augite and amphibole change into zoisite. The alteration of amphibole into epidote has long been known and petrologists are familiar with the fact that epidote and

[1] Principles of N. American Pre-Cambrian Geology, by C. R. Van Hise, p. 690.

and zoisite are often intimately associated together. In the case of the rock under consideration, I think it probable that the hornblende was derived by paramorphic change from augite. On this supposition the variation in the angles of extinction could be easily accounted for. The conversion of augite into hornblende would, we might naturally expect, have been more complete in some crystals than in others.

VOLCANIC ASH.

No. 8—271. Volcanic Ash, from Púga valley, Ladakh; collected by R. D. Oldham, F. G. S.

This specimen is dark green in colour and has a specific gravity of 2·915. Judging from the hand-specimen, the rock either possessed an original laminated structure or a pseudo-lamination has been superinduced by pressure.

The microscopical examination of this rock does not enable me to speak decidedly regarding its origin. It was probably a very fine-grained ash, but, if so, aqueous agents acting on it after its deposition have removed all evidence of its clastic origin. The rock now consists of a very fine-grained mixture of chlorite and microgranular epidote (a variety inclining towards zoisite) dotted with magnetite and an opaque substance, white in reflected light, for which there does not seem to be any definite mineral name. It is a product of decomposition and looks like a cross between leucoxene and zoisite. The slice is much permeated by calcite and contains remains of felspars, some of which are triclinic. The rock is probably a highly altered ash.

No. 8—272. Volcanic Ash, from the Púga valley, Ladakh; collected by R. D. Oldham, F.G.S.; Sp. G. 2·873.

This is a very similar rock to the last. It consists of highly altered felspar crystals, or fragments of crystals, scattered about in a groundmass composed of epidote, chlorite, calcite, ferric oxide, and the white opaque mineral mentioned in the description of the

last slice. The felspars have in part been converted into chlorite and otherwise much altered.

The rock is probably a highly altered ash.

No. 8—275. Volcanic Ash, from Púga valley, Ladakh; collected by R. D. Oldham, F.G.S.; Sp. G. 2·873.

The hand-specimen of this rock is greenish grey in colour and is dotted with black augite crystals. Viewed macroscopically it appears to be an undoubted ash.

The microscope confirms this verdict: but at first sight thin slices of the rock when examined under the microscope are in some respects suggestive of a lava.

Numerous crystals of augite, pale brown in transmitted light, which contain inclusions of the groundmass, are penetrated round their edges by tongues, and closely resemble corroded phenocrysts. This impression is rendered stronger by the fact that the material which forms the inclusions and the tongues is identical with the groundmass itself; and all of it is uniformly dotted with minute spots, or patches, of white and opaque mineral matter resembling leucoxene. The tongues, moreover, are continuous with the groundmass. There is no physical break between them suggestive of clastic structure.

This pseudo-corrosion appears to have been produced in the following way. The original rock, I take it, was composed of augite and felspar phenocrysts imbedded in a glassy or felspathic base, and the phenocrysts of augite contained inclusions of this base. Then came the volcanic explosion that formed the ash. The large augites were broken into fragments and were in their passage through the air abraded at their edges by collision with each other. The material of the groundmass, on the other hand, broke up more easily and formed a very fine-grained dust which by subsequent pressure was forced into tongue-like abrasions in the augite crystals. Lastly, there followed aqueous infiltration that caused a segregation of the

titaniferous-iron in the finely comminuted ash, and in the inclusions of the base in the augites. Opaque spots and patches of leucoxene were thus formed in the groundmass, in the pseudo tongues, and in the inclusions. Aqueous infiltration still further masked the clastic character of the rock by converting what remained of the finely comminuted ash into a chloritic-serpentine, fine canals of which not only meander about in the groundmass, but penetrate the augites from side to side.

The augites are nearly all distinctly fragments, though in one case an idiomorphic crystal remains intact. There are also fragments of felspars. They are much altered and contain patches of chloritic serpentinous material and of calcite, or magnesite, and magnetite. The latter is also common in the groundmass.

The rock under description affords a good object lesson of how aqueous agents, acting on finely comminuted ash, may obliterate evidence of its clastic origin. Where the contact action of igneous intrusive rocks follow the action of aqueous agents still greater difficulties may arise. A really good suite of specimens is *sometimes* indispensable to enable a petrologist to say positively whether a rock is a highly metamorphosed ash or a highly altered lava.

No. 94—218. Volcanic Ash, from Wangat, Ladakh; collected by R. Lydekker, F.R.S.; Sp. G. 2·849. The rock occurs with tertiary strata.

This ash has already been described by me in the Records, Geol. Surv. Ind., Vol. XIX, p. 118 (1886). It is a dark-grey fragmental rock with a slight greenish tinge.

Under the microscope the rock is seen to be made up of subangular and splintery fragments which vary much in size. Some of them are fragments of acid volcanic rocks such as felsite, rhyolitic lava, and porphyry. There are also pieces of quartz, felspar, crystalline limestone, and grains of magnetite and titaniferous iron. It is the two last that give the rock its high specific gravity. If we except the iron, which appears to be an original constituent and

not a secondary product of infiltration, none of the fragments were derived from basic lavas or ultra-basic igneous rocks. I have not detected any ferro-magnesian mineral in the slices cut from this specimen. Besides the above-named rocks the thin slices also contain grains of calcite and fragments of quartz and felspar.

The fragments of which the rock is made up are the reverse of fresh, but the alteration set up in them seems to have taken place before the formation of the ash. The thin slices are not stained or streaked by any visible aqueous agents.

The ash reminds me of the ash-like fragmental rock which occurs in the Gupis-Yasin section of the Yasin valley described in my paper on the Geology of Gilgit (Quart. Journ. Geol. Soc., Vol. 56, pp. 357, 358). They must both have been derived from very similar rocks.

No. 94—224. Fine-grained Ash, from Wangat, Ladakh; collected by R. Lydekker, F.R.S.; Sp. G. 2·75. Said to be of eocene age.

This is a greenish grey and very fine-grained fragmental rock. It is made up of subangular fragments very closely packed together. They are all small, but vary much in relative size. None of them are water-worn and there is no parallelism, or lamination, in their arrangement, the longer axes of the fragments being orientated in all directions.

Some of the fragments can be definitely recognised as lavas, but the majority cannot be identified as such. They consist of angular, subangular, or splintery pieces of quartz, triclinic felspar, crystalline limestone, granite, and schist. Some of the quartz grains contain numerous liquid cavities with movable bubbles and were evidently derived from a granite. Some fragments apparently came from porphyries or rhyolitic rocks.

The slices contain dots and patches of red or dark brown ferrite, but no ferro-magnesian mineral, or fragment of a basic igneous rock. Except in its finer grain, and in the absence of magnetite, it very much resembles the last-mentioned specimen. The fragments are

not fresh and are dotted and streaked with on opaque substance, dead white in reflected light, suggestive of leucoxene.

I cannot say decisively from the microscopical examination of thin slices of this rock whether it is a fine-grained grit made up mainly of fragments of igneous rocks, or whether it is of true pyroclastic origin. Three things, however, may be positively affirmed regarding the rock, namely, that it is of clastic origin; that the materials of which it is composed are not water-worn, and that they cannot have travelled far. Presumably, therefore, it is an ash.

EXPLANATION OF PLATES XVII AND XVIII.

Fig. 1. Shigar bowenite as seen under the microscope between crossed Nicols.

Fig. 2. A fine-grained slice of Afghán bowenite under crossed Nicols.

Fig. 3. Large grained Afghán bowenite seen between crossed Nicols. It is composed of leaves of serpentine (antigorite). On revolving the crossed Nicols, the dark portions become light and the light portions dark.

Fig. 4. Augite partially converted into fibrous serpentine (chrysotile).

Fig. 5. Augite penetrated by large solution veins, filled with fibrous serpentine (chrysotile), continuous with the chrysotile surrounding the augite.

Figs. 1—5 are collotype reproductions of photographs taken by the author. Some of the photographs have been enlarged in order to make the micro-structure visible in the printed plates.

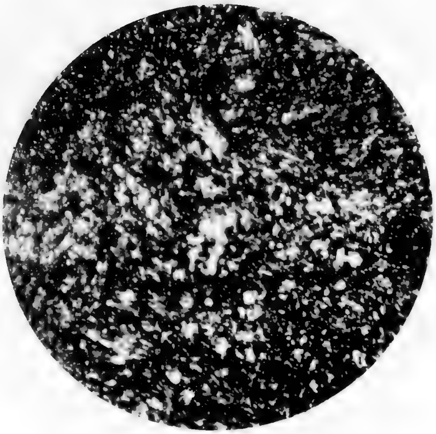

Fig. 1.

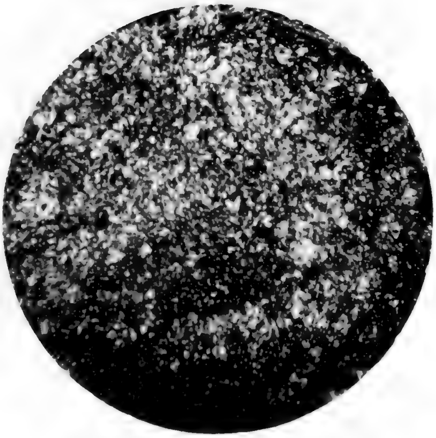

Fig. 2.

Fig. 3.

PERIDOTES AND SERPENTINES OF N.W. HIMALAYA.

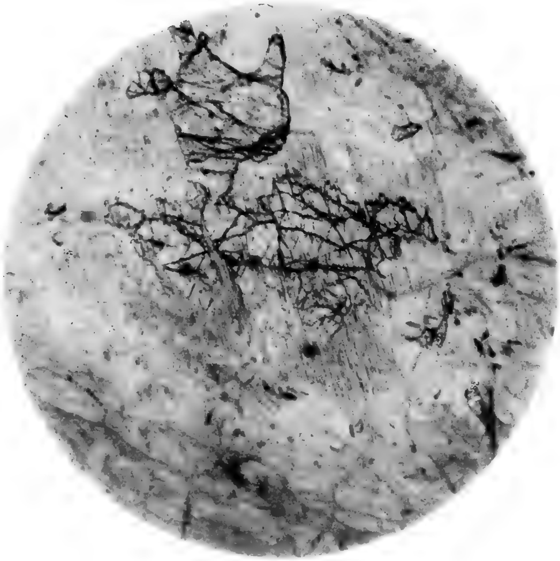

Fig. 4.

Fig. 5.

PERIDOTES AND SERPENTINES OF N.W. HIMALAYA.

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